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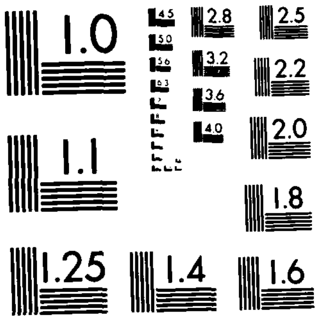

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AN ABANDONED CLIFF IN
WEALD CLAY, NR. LYMPNE, KENT, ENGLAND

Final Report

Principal Investigator: J.N. Hutchinson

July 1984

U.S. Army European Research Office
Contract No. DAJA 37-80-C-0163

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The report describes a detailed surface and sub-surface investigation of an abandoned cliff in Weald Clay. Marine erosion was active at its foot about 5000 years ago, towards the end of the Flandrian transgression. This formed a steep cliff in the Weald Clay. Subsequent slope development has consisted chiefly of colluvium from the higher slopes moving down, spilling over this cliff and eventually burying it. The toe of debris thus formed now extends about 130m seaward across the old wave-cut platform and its associated littoral and alluvial deposits.

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The upper, degradation zone, and lower, accumulation zone, of the abandoned cliff are now of approximately equal inclination, at 9°, although the degradation zone is naturally more hummocky. This indicates that the slope has essentially reached its angle of ultimate stability. This is borne out by the present, rather stable, condition of the slopes.

Valuable data concerning the condition of the slope about 1700 years ago are provided by the associated investigations of the ruined Roman fort, which occupies the central and lower parts of the abandoned cliff. These indicate that the fort was disrupted by a major slide in the accumulation zone, possibly triggered by human activity, in the early post-Roman period.

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AN ABANDONED CLIFF IN WEALD CLAY, NR. LYMPNE, KENT

Final Report on European Research Office Contract DAJA 37-80-C-0163

1. INTRODUCTION

This report describes a geomorphological and geotechnical investigation of an abandoned cliff of Weald Clay near Lympne, Kent, England (Fig. 1). From a study of the present surface morphology together with sub-surface exploration by means of trial pits and boreholes, the nature and geometry of the colluvial and in situ components of the cliff and their relationship to the littoral and alluvial deposits at its foot have been defined. With the aid of dating by radiocarbon assay and by archaeological means, a reconstruction of the development of the cliff since abandonment has been made.

1.1 Site Environs

The abandoned cliff line runs from the present coast at Hythe (NGR TR170 345)[1] to a point inland at Aldington (NGR TR065 365), a distance of 12km (Fig. 2). The cliff is composed of Lower Cretaceous deposits comprising Weald Clay, a clay and clay shale, overlain by Atherfield Clay and capped by the interbedded limestones and weak sandstones of the Hythe Beds. Cliff heights vary from 30 metres (at Hythe) to 150 metres (at Aldington) with up-slope lengths of 200 metres and 800 metres respectively. The abandoned cliff is fronted by the Flandrian littoral and alluvial deposits of Romney Marsh.

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1 Six figure references, to the nearest 100 metres relate to the National Grid. The two letter prefix refers to the 100km square within which the number reference refers.

1.2 Site Investigated

Detailed sub-surface investigations have been made over a length of 0.8km of the abandoned cliff NGR TR 118 343, close to the village of Lympne.[2]

This area was chosen for detailed sub-surface investigation for the following reasons.

a) The abandoned cliff-line behind Romney Marsh is one of the best examples of such a feature in southern England.

b) In the Lympne area, the morphology of this slope indicates that it is in the final stage of development. It thus forms an interesting contrast with the abandoned cliff of London Clay studied previously at Hadleigh, Essex (Fig. 1), by Hutchinson and Gostelow (1976).

c) The presence on the slope of the dislocated remains of the late 3rd century A.D. Roman "Saxon Shore" fort of Stutfall Castle (Portus Lemanis) provides a potential archaeological contribution to the understanding of the slope development.

d) An 11th century manor house on the cliff crest at the eastern limit of the area studied provides evidence for zero or minimal recession of the rear scarp of the landslide system there during the past 900 years.

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2. Pronounced "Limm". "A word you cannot spell if you hear or pronounce if you see" (Ireland, 1823).

e) A failure at the head of the slope is reported to have occured at French House in about 1725, just west of the western limit of the area studied.

2. OBJECTIVES

The study of abandoned cliff lines is not only of major scientific value within the framework of engineering geomorphological research, but is also of direct practical application, as increased pressure on land resources leads to a greater frequency of construction on such quasi-stable slopes.

The specific technical objectives of the research project were.

a) To identify and describe the present day morphology, geology and hydro-geology of the abandoned cliff.

b) To distinguish the colluvial, alluvial and 'solid' parts of the cliff profile, and to sub-divide the various colluvial stages.

c) To describe and date the various phases of colluviation.

d) To make analytical geotechnical studies of the slope movements and to contribute to the improvements of existing models of slope development.

e) To reconstruct the development of the slope since its abandonment and to determine to what extent this was influenced by Post-glacial climatic variations and the Flandrian sea level rise in south-east England.

3. REVIEW OF SLOPE DEVELOPMENT ON ABANDONED CLIFFS

On the cessation of toe erosion, cliffs undergo a process of 'free degradation', solely under the influence of weathering and climate, until a condition of long term stability under the prevailing climatic conditions is reached (Hutchinson 1967). The abandoned cliffs which result have frequently given rise to serious civil engineering problems (e.g. Early & Skempton 1972, D'Appolonia et al. 1967).

Free degradation in cliffs composed of an argillaceous stratum has been most closely studied in the London Clay cliffs at Hadleigh, Essex (Fig. 1) (Hutchinson & Gostelow 1976) and from this work the present understanding of the processes involved can be described. On cessation of toe erosion, rotational landslips reduce the overall slope angle. Initially these movements encroach on the cliff top, but the size of each landslip tends to reduce with the reduction in slope angle and the build-up of debris at the toe so that, at an early stage, a bilinear profile is produced. The steeper, upper part of this, where first-time slipping is active, is termed the "degradation zone": the less steeply inclined and smoother lower part is termed the "accumulation zone". The process continues until, for the London Clay, the slope of the degradation zone declines to about 13°, at which stage the associated landslides are of successive rotational type. This process is essentially completed when the degradation zone has declined to about the same angle as the accumulation zone, i.e. about 8° for the London Clay. With the cessation of sliding movements, the irregularities of the degradation zone slowly become smoothed by hill-wash and soil creep.

The foregoing slope development sequence is implicitly continuous. Detailed investigation and dating at Hadleigh, however, showed that the degradation there was strongly episodic in response to climatic changes since the cessation of toe erosion in the late Devensian (last glacial) Stage of the Quaternary. At present, the slope comprises an actively unstable degradation zone at an overall angle of about 12.5°, and a quasi-stable accumulation zone at an angle of 8°. As the colluvial material within the accumulation zone is strongly weathered, and sheared, and within an area of high ground water levels, this zone reaches the condition of long term stability at an early stage in the development of the slope, and th anticipates the long-term slope angle to which the whole slope v ultimately approximate.

4. HISTORY OF THE ABANDONED CLIFF AND THE MARSH AT ITS FOOT

4.1 Historical Records of Movement Affecting the Abandoned Cliff

The proximity of the coastline to mainland Europe has ensured the military significance of the area. The main phases of activity have been the Roman invasion and occupation resulting in the construction of the Shore Fort in the 3rd century A.D.; the incursion by William in 1066 leading to the construction of the manor house at the crest of the cliff and the Napoleonic invasion scare of the late 18th and early 19th centuries, which resulted in the construction of the Royal Military Canal at the toe of the slope.

The Domesday Book (V.C.H. 1932) of circa 1069 notes the economic value of the community at Lympne but gives no indication as to whether the slope was then under cultivation. During the construction of the 11th century A.D. fortified manor house, Lympne Castle, at the crest of the slope, facing stones from the Roman fort were re-used. The earliest site specific account was published in 1728 by William Stukeley (1728) with an engraving of a view looking upslope to the Roman Shore Fort from the marshes at the slope foot. Allowing for the imagination of the draughtsman, this illustration shows a view rather similar to that of the present day. Stukeley found the fort to be substantially damaged and dismissed the, then current, notion that this was caused by the "Danes"[3] and attributed the destruction to landslip ("tumult of nature").

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3. "Danes" - signifying post-Roman pre-Conquest marauders.

A further account (Collinson 1728) refers to a landslip which occured in about 1725 during a prolonged wet period (possibly associated with the "The Little Ice Age"). This took place 0.8km west of the Roman fort and affected a timber frame farmhouse ("French House") located on the crest of the Hythe Beds escarpment (TR 113 340). It is stated that the total movement was 40 feet (12 metres) and that this occured during the night, without waking the occupants of the farmhouse. This event appears to have been a first time slide involving the crest of the slope and thus to have involved a retrogression of the Hythe Beds escarpment. A further movement, on a smaller scale and not involving a retrogression of the scarp, occured during the winter of 1978 at a location 1 km east of Lympne (TR 134 345), just below the base of the Hythe Beds scarp.

4.2 Development of Romney Marsh

The abandoned cliff at Lympne is closely interrelated with Romney Marsh. A detailed study of the development of this feature and its associated shingle foreland of Dungeness is beyond the scope of this report. However, a simplified outline of the development is presented.

Dungeness comprises a cuspate shingle foreland fronting reclaimed and naturally silted marsh, the main features of which are shown in Fig. 2. Classical references testify to the importance of the Roman port at Lympne, which would have been in close proximity to the Roman Shore fort. It is likely that the Roman port was within the sheltered area of the estuary formed by the sand dunes, possibly in the area marked 'P' in Fig. 3.

The present marshland is divided by an artificial channel ("Rhee Wall"), built possibly in the 15th and 16th centuries, and now infilled and used to carry a road. The purpose of this canal was to intercept drainage from the inland Wealden area and permit the reclamation of the marsh areas. The area to the south-west of the Rhee Wall was reclaimed in small rectangular areas ("innings"), whilst to the east reclamation took place in a more haphazard fashion, final protection from flooding of the area around Dymchurch, some 3-4km south-east of Lympne, being provided by the construction of a sea-wall in the 1860's.

William Dugdales' account (1662) includes a map of the Dungeness Foreland which indicates an inlet running along the toe of the slope from Hythe to a point west of Lympne. The presence of an inlet at this point is also implied by Elizabethan records and is indicated by the soil-survey of the marshland. The mouth of this estuary was partially blocked by sand dunes by at least the late Saxon period (5th - 6th century A.D.) (Fig. 2).

More recent investigations have concentrated on the shingle foreland (e.g. Lewis 1932), on the development of shingle ridges ('fulls' oblique to the present coastline and on the mapping of soil types within the marsh areas (Green 1965). Accounts synthesizing available information have been published by Steers (1968) and Cunliffe (1980a). Cunliffe's account is concerned with the marsh fronting the slope at Lympne and is based largely on the work of Green.

Of significance to the study of the development of the slope at Lympne is the onset of the condition of zero toe erosion, from which point the slope degrades until a condition of long term stability is attained. Whilst it may be convenient to consider a slope as being subject to either full, or zero

marine toe erosion, the situation at Lympne is more complex. There the toe erosion probably diminished to zero over an extended period as a result of increasing protection from the predominantly south-westerly storms afforded by the development of shingle bars offshore. In the shelter of this proto-Dungeness foreland a wide, sheltered bay was formed into which the rivers Rother, Tillingham and Brede discharged (Fig. 2). Further growth of the shingle accumulation, coupled with siltation in its lee, concentrated drainage to a swale running along, or close to, the toe of the slope and leading to the sea near Hythe. Redirection of the drainage possibly influenced by the construction of the Rhee Wall led finally to the silting up of this inlet (Fig. 3).

5. MORPHOLOGY OF THE ABANDONED CLIFF

5.1 Topographical mapping

A base map of the detailed study area was prepared by photogrammetrically enhancing the 1:2500 Ordnance Survey map to give a contour interval of one metre. Commercially available orthopositives were used. Ground control and accuracy checks were made using EDM trigonometrical levelling and base line measurement. From the 1:2500 map a 1:1250 base map was prepared using photographic enlargement. Field survey checking indicated an accuracy in position of $\pm$ 0.15 metre and in level of $\pm$ 0.1 metre.

Consideration was given to establishing reference points on the fort walls to determine any continuing movement. An error analysis indicated, however, that the detection of movements would not be possible within the time framework of the investigation.

5.2 Morphological Mapping

Using a short range optical range finder with automated plotting, a morphological map was prepared at a scale of 1:1250, using the methods proposed by Savigear (1958).

This technique of mapping breaks in slope and measuring slope angles with a pendulum clinometer worked well except in the case of lobate relic mudslide features, where breaks in slope were not readily definable. In this situation, closely spaced contours are more useful, though a vertical

interval of less than one quarter the relief amplitude of the feature is required and in an area of muted features this may not be practicable.

Conventionally the morphological base map is used to prepare an interpretative engineering geomorphological map (e.g. Brunsden & Jones 1972). In practice it was found that the distinction between the two processes became blurred, as in the first stage some interpretation, if only as to the size of the relevant morphological unit to be mapped, is implicit. Thus the final interpretative map is 'conditioned' by this process.

Fig. 5 is a much reduced copy of the engineering morphological map. For legibility some simplification has been made.

5.3 General Morphology of the Abandoned Cliff

The abandoned cliff divides the Hythe Beds plateau from the marsh. The regional dip of approximately 1° to the east results in the overall cliff height reducing in an easterly direction from 150 metres at Aldington to 30 metres at Hythe. The cliff line consists a steep ($+30^{\circ}$) escarpment in the Hythe Beds caprock, with a shallower slope running down to the marsh across the outcrop of the Atherfield Clay and the Weald Clay. Overall slope angles are typically between 9 and 10°. Running parallel to the slope a short distance seaward of its foot is the early 19th century Royal Military Canal.

The scarp is curved in plan to form two major embayments at Port Lympne and Shepway Cross with an intervening headland on which the village of Lympne and Lympne Castle have been built (Fig. 2). In detail,

the scarp also exhibits a series of smaller-scale indentations, of the order of tens of metres across. These features become more marked to the east.

The slope morphology generally becomes less hummocky and more subdued in an westerly direction from Aldington to Hythe. This is concordant with the cessation of active marine erosion having occured earlier in the west, due to the growth of the shingle foreland, so that these areas have been able to reach a condition of long term stability; whilst to the east of Lympne this state has not yet been reached. This simplified model is complicated somewhat by the presence of more arenaceous formations in the lower Weald Clay which appear in the toe of the slope to the west of Lympne.

The topography and morphology of the study area are shown on Figs. 4 and 5. The height difference between the marsh and the crest of the slope is approximately 95 metres, with an overall slope length of 600 metres. The inclination from the slope toe to the base of the Hythe Beds escarpment is 9°, the slope being uniform rather than bilinear. On the upper part of the slope, springs issue between about +77 m O.D. and +84 m O.D.[4]

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4. O.D. = Ordnance Datum, which is mean sea level at Newlyn, Cornwall.

6. SUB-SURFACE INVESTIGATION

6.1 Shallow Sub-Surface Investigation

Objectives of this phase of the investigation were.

a) To determine the general geology within the area, in particular the location of the boundaries of the Hythe Beds, Atherfield Clay and Weald Clay.

b) To determine the form, thickness and interrelationship of the colluvial units.

c) To investigate the colluvial/alluvial boundary at the toe of the slope.

As the immediate area of the Roman Shore fort is a Scheduled Ancient Monument, the initial phase of trial pitting was concentrated on a broad section immediately to the west of the fort. A total of fourteen pits were dug to a maximum depth of 3.2 metres and logged over a two week period, at locations shown on Figure 4. Subsequently excavations were made within the area of the Roman fort in collaboration with the Institute of Archaeology, Oxford.

The results of this phase of the investigation are detailed in Section 7 of this report. Logs for trial pits 16 and 12 are shown on Fig. 6.

6.2 Deep Sub-Surface Investigation

A total of 23 boreholes were sunk using conventional shell & auger techniques, with continuous undisturbed core sampling, at the locations shown on Fig. 4.

The objectives of this aspect of the investigation were.

a) To extend the depth of investigation into in situ material on the study section and to delineate the colluvial/'solid' interface.

b) To investigate whether lithological variation within the in situ Weald Clay might have had an influence on slope development.

c) To obtain further information on the inter-relationship of the various colluvial units and to recover datable organic material.

d) To install pore water pressure monitoring equipment.

Consideration was given to the installation of inclinometers, but it was considered that within the timescale of the research any movement would probably be too small to be measurable. A total of eighteen piezometers were installed at locations within the colluvium and the underlying solid strata. Mandrels (or "poor-boys") to detect lateral movement were installed in the deeper piezometer tubes.

The results of this phase of the investigation are given in Section 7 of this report. Logs for boreholes 16 and 22 are shown on Figs. 7 and 8.

7. ENGINEERING GEOLOGY AND GEOMORPHOLOGY

For convenience, the solid strata, the colluvium, the alluvium and the hydrology are dealt with separately. Fig. 9 shows the main study section.

7.1 Solid Geology

The Hythe Beds comprise well-cemented, grey-brown, glauconitic sandy limestone ("ragstone") interbedded with yellowish brown to brown calcareous glauconitic sand or weakly cemented sandstone ("hassock"), passing down at + 87.5m O.D. to yellow brown, clayey sand, in turn overlying stiff bluish grey fissured silty sandy clay at +85.25m O.D. The junction of the Hythe Beds with the underlying, stiff, grey-brown fissured silty clay of the Atherfield Clay is situated at +83.5 m O.D.

The junction of the Atherfield Clay and the underlying Weald Clay was found in borehole 9 at about +70 metres O.D. (Fig. 4). Twenty metres further downslope this contact was found to be 1.5 metres higher, suggesting the presence of an escarpment bulge. A similar feature, though on a larger scale, was found in the geologically analogous inland slope at Sevenoaks (Skempton & Weeks 1969), where is resulted from massive blocks of Hythe Beds subsiding into the Atherfield and Weald Clay and forcing up a bulge at the foot of the scarp. At Sevenoaks this structural disturbance was assigned to the Wolstonian (penultimate glacial) Stage of the Quaternary.

The Weald Clay comprises a sequence of sedimentary cycles, each consisting of bioturbated laminated silty clays passing up into black fissile

clays. The overall thickness of each cycle varies within the range of 3 to 4 metres. In the upper part of the formation the cycles are less well developed. Thin limestone bands, with a maximum thickness of 75mm, occur within the Weald Clay. Towards the base of this formation, the presence of more arenaceous facies produces a toe feature at Port Lympne about 1.5 km to the west. The regional dip carries this material below marsh level at Lympne where lithological variations in the Weald Clay do not appear to be manifested in the slope morphology.

7.2 Colluvium

By analogy with the slopes further to the east, and the situation at Hadleigh, it was expected that rotational slips involving the Hythe Beds and extending into the Atherfield Clay, and possibly the Weald Clay, would be found immediately downslope of the scarp. Boreholes 9, 13, 14 and 10 (Figs. 4 and 9), which were carried down into the Weald Clay, showed that in this vicinity the slip movements were seated in the Atherfield Clay.

The absence of clear morphological evidence of rotational slips in the upper part of the degradation zone on the main section line is considered to be the result of natural degradation and subsequent human activity. In this connection the bench-like feature which occupies the foot of the scarp (Figs. 4, 5 and 9) is particularly noteworthy. This coincides in level with the base of the "rag and hassock" sequence of the Hythe Beds and boreholes and trial pits show that it is formed of up to about 3 m of unstratified friable brown silty clayey sands, of very different character to any of the colluvium seen in the slope. Taken together, this evidence strongly suggests that this area of the slope is the former site of a quarry

from which stoney Hythe Beds ("rag") material was taken, possibly, in the first instance, for the construction of the nearby Roman fort.

Just downslope of this bench, the colluvium has a thickness of 2.5 metres decreasing to only 1.7 metres at a point 50 metres upslope of the north wall of the fort. The morphological mapping (Fig. 5) indicates this area to be at about the transition from sharply defined, shallow slide movements upslope to more subdued features downslope, which is taken to be the boundary between the degradation and accumulation zones. The minimum thickness of colluvium in the London Clay slope at Hadleigh (Hutchinson & Gostelow 1976) was within a morphologically analogous area at the break in slope between the degradation and accumulation zones.

Just to the east of the main section line, a pronounced downslope ridge runs down the slope. This extends from the base of the Hythe Beds scarp to a point approximately 100 metres upslope of the north wall of the Roman fort and separates the zone of mainly bench-like successive rotational slides to the west from an area where such slides, associated with the stream to the east (Fig. 5) form a mosaic pattern. Trial pits A and B (Fig. 4) were dug into the ridge and showed it to consist of 0.8 metres of ragstone rubble overlying massive Hythe Beds material. Dip measurements indicate these Hythe Beds to have been tilted and rotated. The ridge lies between two stream systems on the slope and is thought to represent a remnant of an earlier colluvial slope, now bounded to each side by areas of more recently active slipping associated with these stream systems.

In the accumulation zone, the generally smooth and subdued morphology is interrupted in an area just downslope of the north wall of the fort by a

group of west-east trending scarps. Such scarps are not typical of accummulation zones: they are discussed subsequently. The maximum downslope extent of the colluvium is defined by a slight but distinct toe feature fronted the the Marsh.

The thickness of the colluvium in the accumulation zone increases downslope from its minimum value of 1.7 m by borehole 12 to about 6 m at borehole 8. From there it increases rapidly to a maximum of about 19 m at borehole 21 where it buries a former sea cliff. This was cut into in situ Weald Clay, with its foot at around -1 m O.D. The buried cliff is itself inclined at an angle of about 30°. From the foot of this cliff, the thickness of colluvium reduces uniformly to the toe.

7.3 Littoral/Alluvial deposits on the wave-cut platform

The buried cliff is fronted by a wave-cut platform, formed in the Weald Clay at an elevation which varies from -1 m O.D. at the cliff foot to -5 m O.D. at borehole 1 (Fig. 9). The time of formation of this platform is of great importance and may inferred from its relationship to present-day mean sea level. A close analogy to the Lympne wave-cut platform is provided by a similar, active feature in the London Clay on the north coast of the Isle of Sheppey (Fig. 1), where the angle formed between the wave-cut platform and the cliff is situated at 2m above present mean sea level. Although differences in degree of exposure and in tidal range between the two sites preclude a precise comparison, this would indicate that, at the time of formation of the buried cliff at Lympne, mean sea level was about 3m below O.D. Fig. 14 shows a composite curve of Flandrian sea level rise with time. From this, it can be seen that the platform at Lympne was probably cut to its present level around 5000 B.P.

Resting on the wave-cut platform are littoral sands and gravels which in turn are overlain by estuarine alluvium. A water-worn fragment of Roman tile was found in the littoral deposits at borehole 1. This indicates, inter alia, that the estuarine alluvium is largely or wholly post-Roman. Both of these Holocene deposits are now overridden by colluvium for a distance of 135 m. At borehole 1, the wave-cut platform is located 7.6 m below present ground level, and is overlain by 3.1 m of littoral sands and gravels which are in turn overlain by 4.5 m of alluvium. An examination of the mollusca on a profile within the upper part of the alluvium in trial pit 11 indicated an upward transition from marine, through brackish, to freshwater conditions (R. Preece, pers. comm.). A similar transition was noted some 300 metres to the east of the study section (Cunliffe 1980b).

7.4 Dating of Colluvium

During the borehole investigation a number of samples of organic material were recovered from undisturbed core samples of the various colluvial units. A total of ten of these were accepted by the Natural Environment Research Council for dating by radiocarbon assay at the NERC Radiocarbon Laboratory. The table below gives the results of the assays, the locations of the samples being shown on Fig. 9. Dates are uncorrected and based on a half life of 5570 $\pm$ 30 years, and given in years before present (1950 A.D.).

NERC Ref. No.	BH	Depth	Age in Years BP
SRR-2292	6	9.26 - 9.34	>43900 ($d^{14}C$=-1001. 9+1.1‰)
SRR-2293	6	12.70 - 13.30	7970 ±80
SRR-2294	6	14.50 - 15.10	4120±50
SRR-2295	18	7.70 - 8.30	3420±50
SRR-2296	18	12.40 - 13.10	4360±50
SRR-2297	18	12.40 - 13.10	3680±120
SRR-2298	18	21.2 - 21.40	> 44,200 ($d^{14}C$=-999. 2±1.0‰)
SRR-2299	20	5.26 - 5.60	3290±70
SRR-2300	22	2.10 - 2.60	2010±70
SRR-2301	19	17.80 - 18.00	4400±50

The dates of >43900 for samples SR-2292 and SR-2298 represent infinite dates and indicate that the samples submitted were not of Quaternary age but were fossil timber or fusain derived from the Atherfield Clay and/or the Weald Clay and incorporated into the colluvium. Fusain was found within undisturbed core samples of in situ Weald Clay and also is known to occur within the Atherfield Clay in East Kent (R. Lake, pers. comm.)

Sample SRR-2301 was a log of wood from the lowermost colluvium at the base of the buried cliff and is dated to 4400 ± 50 years B.P. This shows that, by then, the intensity of marine erosion had reduced to such an extent that colluvium spilling over the cliff was not removed. The close proximity of the then, contemporary shore line is attested to, however, by the water-worn fragment of Roman tile in the basal littoral sands and gravels overlying the wave-cut platform. As shown by Fig. 9, a sample within the colluvium about 50m south of the toe of the burried cliff yielded a date of 7970 ± 80 years B.P., indicating that a considerable movement of older colluvium from upslope has occurred.

The colluvial material below the crest of the buried cliff was largely emplaced within the period 4400 BP - 3420 BP. This lower colluvium is predominantly of Weald Clay origin with occasional traces of Atherfield Clay, and is typified by a highly sheared fabric and a complete absence of Hythe Beds derived material. A break in colluviation at around 3200 BP occurs at a marked lithological change to, overlying, predominantly Hythe Beds derived colluvium. In this upper colluvium the more clayey parts have a mudslide fabric with peds of intact materials. A similar fabric occurs in active coastal mudslides in London Clay (Hutchinson 1970). The uppermost colluvial unit is continuous over the whole of the accumulation zone and comprises silty clays with fine, loamy, glauconitic sands and angular unweathered ragstone blocks. Downslope of the north wall of the Roman fort, cobble to boulder-sized ragstone blocks occur close to present day ground surface, and are likely to be construction debris, or eroded material, from the Roman fort.

8. GEOTECHNICAL INVESTIGATION OF THE FORT AREA

As previously stated, a primary reason for the choice of the slope below Lympne for detailed investigation was the presence on the slope of the dislocated remains of a late 3rd century A.D. Roman fort. From a knowledge of the construction dates, and by establishing the original plan of the fort, movement vectors covering 1700 years could be deduced and the processes that resulted in the destruction of the fort thus clarified.

Following the sub-surface investigations on the main section immediately to the west of the fort, a plan was formulated for sub-surface investigation within the fort, to be carried out in collaboration with the Institute of Archaeology, Oxford. The support and assistance of Professor B.W. Cunliffe and his Research Assistant, Cynthia Poole, in this work is gratefully acknowledged. Formal permission to excavate within the area of the Scheduled Ancient Monument was obtained from the Department of the Environment.

The specific objectives of the investigation were.

a) To determine the original plan of the fort, and its position on the slope.

b) To determine the nature and depth of the fort wall foundations.

c) To elucidate the nature of movements affecting the fort.

From our previous sub-surface investigations, it was apparent that the greater part of the fort walls were likely to have been founded on colluvium, and hence their original position would be difficult to determine. Accordingly, investigations were concentrated on the north wall of the fort where the colluvium had been found to be thinnest.

8.1 Geophysical Survey

A resistivity survey was first made of an area extending 120 metres upslope of the north wall of the fort to ascertain the possible location of any masonry foundations that might still be *in situ*. The survey indicated no clear resistivity anomalies over the range of expected foundation levels and suggested that any post-Roman movements had moved the north wall as a complete unit and not sheared the upper part from its foundations.

8.2 Fort Survey

Preparation of an acceptable survey of the fort was not possible using the available photogrammetry. An accurate survey of the fort, to a scale of 1:200, was therefore made using E.D.M. survey equipment.

8.3 Methodology

Exploratory trenches were excavated by machine and strutted. Geotechnical elevations of the pit faces were made at a scale of 1:20. Cynthia Poole carried out the archaoelogical logging.

8.4 Results and Discussion

Excavations were made at the locations shown on Fig 10. The first trench, TR 101 (Fig. 11), was dug on the upslope face of the north wall of the fort and extended upslope. The original piled foundations of the wall were exposed and found to have been driven into the in situ Weald Clay. This made possible the determination of both the original position and form in plan of the northern part of the fort.

8.4.1 Wall Foundation Details

The foundation piles exposed were of oak. They varied in diameter from 100 to 350mm, had carefully pointed ends, and were driven in a staggered arrangement at approximately 400mm centres. The piles extracted (4 No.) appeared to be in sound condition and had lengths varying between 0.6 and 1.8 metres. Piles were found in the excavations on the north wall and on the north-west wall close to Bastion 5. In all these excavations the piles had been driven into in situ Weald Clay, which enabled the original position of these sections of wall to be determined. Around the tops of the piles a ragstone rubble packing had been placed to form a level platform for wall construction. The foundation to the wall comprised ragstone flags set in mortar, reducing in steps to the above-ground wall thickness of approximately 1.8 metres. The wall comprised a concrete and rubble filled core with dressed ragstone facings. In the lower part of the wall the mortar was pink in colour through the addition of powdered tile. This feature has been found at other similar forts (Cunliffe 1980) on parts of walls situated below ground level. It was not possible to examine the underside of the wall foundations to determine whether the piles had been socketted into the base.

8.4.2 Mode of Failure of North Wall

The excavations showed that the north wall of trench 101, had moved downslope by a distance of about 3.5 m from its original position and tilted downslope by 20° in the process. From Fig. 11 it can be seen that while the upslope piles had remained essentially undisturbed and vertical, those downslope had been forced over almost to the horizontal. This indicates failure had been initiated with a forward tilting movement, followed by a combination of tilting and translation. A considerable difference in ground level across the wall is thus implied. This might have resulted from either a build-up of colluvial material upslope of the wall, a removal of material downslope by landslipping, or a combination of these. Fig. 14 shows a reconstruction of the mode of failure of the north wall, made on the basis of the results of the excavations.

8.4.3 Excavations at Bastion 3

An excavation, TR 103, (Fig. 10) was made on the west face of Bastion 3. The bastion had been subject to a complex sequence of translational, rotational and tilting movements. Its base was found at 4 m below present ground level.

8.5 Original Plan of the Roman Fort

Two as-built plans have been suggested by previous investigators.

1) An originally rectangular plan with the north wall built in approximately its present position, with Bastion 3 having moved downslope a distance of around 65 metres (Cunliffe 1980b).

2) An originally polygonal plan, with the north, west and east walls built in approximately their present positions (Roach Smith 1852).

The positions of the most upslope in situ piles were determined in trenches TR101 and TR106. From these the original line of the north wall between Bastions 5 and 6 was located. Pile positions in trenches TR105 and TR108 were similarly located allowing the determination of the original line of the north-west wall from Bastion 5 towards Bastion 4 (Fig. 10). It was thus demonstrated that these walls met at Bastion 5 with an internal angle of approximately 140°.

A further trench TR107 was dug in an attempt to trace the line of the north-west wall further downslope, though with hindsight it is clear that this pit was dug just too far to the north.

The pattern that emerges is of a non-rectangular fort (Fig. 10), the north wall having moved downslope 3.5 metres and the north west wall at Bastion 3 some 25-35 metres. From all the available evidence, the reconstruction of the original plan fort shown in Fig. 10 has been constructed.

8.6 Post-Roman Movements

Subsequently to the construction of the Roman fort (late 3rd century A.D.), a major translational movement has affected the slopes beneath the north wall of the fort. This had a maximum downslope movement of 25-35 metres and caused serious disruption to the east and west walls of the fort and some displacement and tilting of the north wall.

Movement of such a magnitude, within the accumulation zone, is difficult to reconcile with the usual model of slope development, in which the accumulation zone tends to maintain an angle close to that for overall long-term stability. In the present case, there is also the point that the Roman engineers would have been unlikely to have chosen a patently unstable slope on a site for the fort.

The date of this slide is of key interest in the development of the slope and may help to throw light on the cause of the movement. The available evidence is summarised below.

1. The late 3rd century A.D. fort was abandoned earlier than other Saxon shore forts, in about 340 to 350 A.D. (Cunliffe 1980): this may have been due to landslide damage.

2. Stukeley's engraving of 1728 shows that, by this time, the major movements affecting the fort had taken place.

3. The facing stones of the fort have been robbed for use in other buildings. This robbing has taken place from those sections of the disrupted fort largely above present ground levels. If the robbing was primarily associated with the construction of Lympne Castle in the 11 to 12th centuries A.D., this would suggest that ground levels then were broadly similar to those of today and that the major movements had already taken place.

From the above, the date of the major slide must lie between about the early 4th and late 17th centuries A.D. and there is some indication that it

occurred in the early part of this period. A possible trigger for the slide is human interference, for example:

1. Clearance of the site and the use of locally obtained timber in construction of the piled foundations and internal buildings might have removed trees present and resulted in some increase in ground water levels and hence pore-water pressures within the area of the slip.

2. The siting of the Roman fort at Lympne was of strategic importance as it controlled the estuary into which the main rivers from the iron-producing Weald flowed. Silting of the estuary would have been of concern to the Romans and it is possible that some attempt would have been made to clear it. That the Romans were capable of dredging is confirmed in Plutarch's Caesar where reference is made to the dredging of offshore shoals at Ostia to improve the port (C. Poole, pers. comm.). Any dredging close to the toe of the Lympne slope may have acted as a trigger for the slide.

3. The toe of the slope may have been cut back to improve the defensive capability of the south wall or to permit the construction of harbour works, thus removing toe support from the accumulation zone.

9. GEOTECHNICAL ANALYSIS

9.1 Laboratory Testing

A programme of residual strength testing was carried out on samples obtained during the sub-surface investigations. Routine classification tests were also made, the liquid limit being determined using the cone-penetrometer method, and the clay fraction (% $< 2 \mu m$) using the sedimentation method. A total of 27 tests were made to determine the residual strength of the soil in the Bromhead ring shear apparatus (Bishop, et al. 1971, Bromhead 1978). Fig. 12 presents a summary of the test results.

9.2 Stability Analyses

Stability analyses in terms of effective stress have been made of the various failure surfaces shown in Fig. 13. These have been chosen to follow the actual or inferred slip surfaces revealed during the sub-surface investigations. An average unit weight of $18.5kN/m^2$ for the colluvium has been used throughout. Two piezometric lines have been used, the highest recorded winter level in the piezometers and a piezometric line coincident with ground level. Stability analyses have been made using the method of Morgenstern & Price (1958). In view of the high breadth/length ratio of the movements on the main section, no correction for side friction has been made. Additional analyses, in terms of effective stress, have been made using the infinite slope method. Analysis of first time rotational slides affecting the Hythe Beds escarpment have been made using the Bishop Simplified Method (Bishop 1954). All the failure surfaces

considered, with the exception of those for the first-time rotational escarpment movement, are pre-existing and are thus at, or close to, to their residual strength.

Inference of field residual strength from stability analyses assumes that the factor of safety is unity. The field evidence indicates that factors of safety are lowest over the upper part of the slope in the degradation zone and probably only marginally in excess of unity under present-day winter conditions. A factor of safety of unity has been assumed for these surfaces and the analyses used to construct a field strength envelope for failure on pre-existing slip surfaces. Due to the shallow nature of these slides it is only possible to obtain data over a low normal effective stress range (up to $60kN/m^2$). Whilst the field evidence indicates that the factor of safety of the lower part of the slope is greater than unity there is difficulty in calculating the actual factor of safety. Measurements of residual strength show a considerable variation along the slip surfaces and it is not possible to determine a reliable average value for the failure surface to compare with the value inferred from back-analysis.

9.3 Discussion of Test Results

With the ring shear apparatus, relative displacement on the shear surface may be continued indefinitely by rotation of the plattens, thus allowing the true residual strength of the soil to be measured. Field strengths inferred by back analyses are generally higher than those measured in ring shear. This is in part due to the uncertainties in the analyses, i.e. the neglect of side forces and internal work, but also to the limited number of ring shear tests made, usually on 'worst' rather than "average" samples (Bromhead & Curtis 1983), and the planar nature of the test shear surface

which contrasts with the non-planar surfaces sometimes found in the field. Fig. 12 shows the results of the ring-shear tests plotted in terms of normal stress against the ratio of shear to normal stress.

10. SLOPE DEVELOPMENT AT LYMPNE

10.1 General

The investigations have shown that the present morphology of the slope at Lympne is largely a result of slope development over the last 4000 to 5000 years. The earlier history of the slope may be explored in the light of established Quaternary climatic and sea-level changes and by analogy with the inland continuation of the Lower Greensand excarpment near Sevenoaks, Kent (Fig. 1).

During the Quaternary, ice sheets advanced into England on at least three occasions but did not extend south of the line of the River Thames (Fig. 1). Thus the present site has never been glaciated, but has experienced intense periglacial conditions on several occasions. The following table outlines the relevant Quaternary history.

Stage	Age/Years	Climate	Sea Level
Flandrian	0-10,000 app.	temperate (? interglacial)	recovery to present day m.s.l.
Devensian	10,000 - 70,000 app.	Periglacial conditions in south-east England	depressed by up to ca. 120m.
Ipswichian	70,000 - 95,000 app.	temperate (interglacial)	max. ca 7.5m above present
Wolstonian	95,000 - ?150,000	intense periglacial conditions in south-east England.	strongly depressed by more than 150m

10.2 WOLSTONIAN

During the Wolstonian glaciation, sea level was strongly depressed so that the cliff at Lympne would have been well inland. At Sevenoaks, major structural disturbances affecting the escarpment of the Hythe Beds have been dated to the Wolstonian (Skempton & Weeks 1969). Whilst there is no evidence at Lympne for such disturbances the minor bulging of the Atherfield Clay immediately below the escarpment and the remnant block of Hythe Beds forming the downslope ridge (Fig.5) are suggested by field evidence to predate the minor translational and rotational movements within the scarp embayments.

10.3 IPSWICHIAN

During the Ipswichian interglacial, sea level rose to a maximum of ca + 7.5m O.D., forming the "twenty-five foot" raised beach which can be traced eastwards along the south coast to Black Rock, near Brighton (Fig. 1). At Lympne, such a feature would have been expected to have been formed at a similar level.

10.4 DEVENSIAN

During the Devension glaciation, sea level was depressed by at least 120m below its present level so that the Lympne slope would again have been remote from the sea. Whilst the subsequent (Flandrian) recovery of sea level has led to the removal of any deposits formed on the slope during this period, two major solifluction sheets have been recognised at Sevenoaks. The lower extended some 500 metres from the foot of the scarp on slopes of 3-4^{o}. This was separated by a palaesol dating to the

Late Devensian Interstadial (*ca* 12,000 BP), from an overlying solifluction deposit extending 300 metres from the foot of the scarp on slopes of *ca* 7^{o} and dated to the Zone III of the late-glacial (Younger Dryas). It is likely that a similar sequence of solifluction occured at Lympne so that, at the close of the Devensian, the slope there would have been mantled by solifluction sheets extending some distance to the south of the present toe of the slope and burying any cliff cut in the Weald Clay during the Ipswichian interglacial.

10.5 FLANDRIAN

The Flandrian sea level rise led initially to the erosion of the solifluction sheets extending southwards from the present toe and then to the formation of the now buried cliff in the *in situ* Weald Clay revealed by our investigations. During this process, any Ipswichian cliff line would have been exhumed and removed. Around 4400 BP, the development of a shingle bar eastwards from Fairlight Head (Fig. 1) reduced the intensity of marine erosion until a point was reached when it was no longer able to remove the colluvial material spilling over. Further growth of the shingle mass concentrated drainage, flowing from the inland Weald, to a swale[5] running along the toe of the slope to an outlet to the sea near Hythe, 5km to the east of Lympne.

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5. A broad, shallow, sheltered natural channel.

11 THEORETICAL MODELS OF SLOPE DEVELOPMENT

The simplest geometrical models of slope development applicable to the study of abandoned cliffs are those which attempt to predict the evolution of an initially rectilinear free-face. The classic model is that of Fisher, as modified by Lehmann, termed the "Fisher-Lehmann" model (Fisher 1866, Lehman 1933). The key features of this are shown on Fig. 16. The model rests on the assumption that the debris wedge at the toe of the free-face grows at a constant inclination and that no further modification occurs to the portion of the free-face buried by this debris. The further assumption is made that the transfer of weathered material to the debris pile occurs by infinitesimally small increments. Thus the model is one of parallel rectilinear slope recession. It can be shown, for an initially vertical cliff and zero bulking, that the shape of the resulting rock core is that of a parabola. The Fisher-Lehmann model was developed from studies of chalk cliffs and it is thus not directly applicable to overconsolidated clay slopes. However, of more general applicability is the implication that the slope of the pile of weathered debris will anticipate, at an early stage, the final overall slope angle. This has has been shown to apply to the accumulation zones below freely degrading London Clay cliffs, for instance, at Hadleigh (Hutchinson & Gostelow 1976). The Bakker & Le Heux (1947) model of central rectilinear recession modifies the assumption regarding weathering on the free face, in that the depth of weathering at any point on the free-face is assumed to be proportional to its elevation. Fig. 16 shows the main features of this model, from which it can be seen that the free-face remains rectilinear but declines in angle, by rotation about a basal point, as the slope develops.

All models of this type yield broadly similar results regarding the form of the buried core, which is convex upwards and tangential to the initial free-face angle at the foot of the cliff, reducing eventually to a slope equal to that of the debris pile at its uppermost point.

The Bakker & Le Heux model was examined by Hutchinson & Gostelow (1976) in the light of the results of their investigations at Hadleigh. It was demonstrated that although the models have a degree of application to stiff clay slopes, the predictions concerning the shape of the intact core were inapplicable in detail at Hadleigh, where changes in the degradation zone are effected mainly by episodic, moderately deep-seated rotational landslips.

The models of Fisher-Lehmann and Bakker & Le Heux are primarily concerned with the shape of the buried core and whilst attempts have been made to extend the theories to explain the surface profile of slopes, these have not been particularly successful. Further models have attempted to predict the development of the surface profile by making assumptions as to the nature of the denudation process acting on the slope. Such models are discussed, for example, by Carson & Kirkby (1972) and by Scheidegger (1970), who considers the cases of undercutting and lithological variation due to the presence of a cap-rock.

A further group of models of slope development is based on the application of geotechnics to slopes. This has been most comprehensively applied to the abandoned cliffs in London Clay at Hadleigh, as described earlier in this report. For an homogenous clay slope a condition of long-term stability, under the prevailing climate, is dependent on the residual strength parameters of the soil and the hydrogeological regime. The

ultimate angle of stability is approximately 8° for the London Clay (Hutchinson 1967). At Lympne, the slopes have apparently reached a condition of long-term stability, as the inclinations of the accumulation and degradation zones (excluding the relatively thin capping of Hythe Beds) are about equal. The angle of ultimate stability for this predominantly Weald Clay slope is around 9°. That this is a little higher than the value for the London Clay is constant with the generally rather lower plasticity of the Weald Clay.

At Lympne, it seems likely that a fairly classic, Hadleigh type of slope development may have been taking place up to the period, around 4500 years B.P., when the, now buried, sea cliff was eroded at the slope foot. Since then, the steep cliff of Weald Clay thus formed appears to have remained stable and the subsequent slope development has resulted almost entirely from colluvium from the higher slopes spilling over and successively burying this cliff and thus re-establishing the accumulation zone. Clearly the mode of emplacement of such an accumulation zone is radically different to that found at Hadleigh.

12. MAIN CONCLUSIONS

1) The most recent phase of marine erosion at Lympne has cut a, now buried, cliff into in situ Weald Clay, fronted by a wave-cut platform. The elevation of this wave-cut platform indicates it to have been formed around 4500-5000 years B.P. This is concordant with a radiocarbon date of 4500 B.P. for a log found in the colluvium at the base of this cliff.

2) The present morphology is partly a result of slope-forming processes acting since the cessation of marine erosion ca 4500 years B.P. and partly inherited from the previous phase of development.

3) At a somewhat late stage in the development of the slope a translational landslip occured within the accumulation zone resulting in serious disruption to the Roman fort that had been constructed there in the late 3rd century A.D. This movement is indicated by historical evidence to have occured somewhere between the early 4th and late 17th centuries A.D. There is reason to believe that the landslip occurred in the early part of this period, possibly as a result of human inteference.

4) The most recent major movement, on the upper part of the slope and possibly effecting a further retrogression of the Hythe Beds scarp, occured in the early 18th century during a period of wet and cold climate.

5) The accumulation zone has essentially reached a condition of long-term stability.

6) Within the degradation zone, movements have been confined to those of shallow rotational type, and some minor movement is probably continuing during prolonged wet periods.

7) The ultimate angle of stability of the Lympne slope is about 9°.

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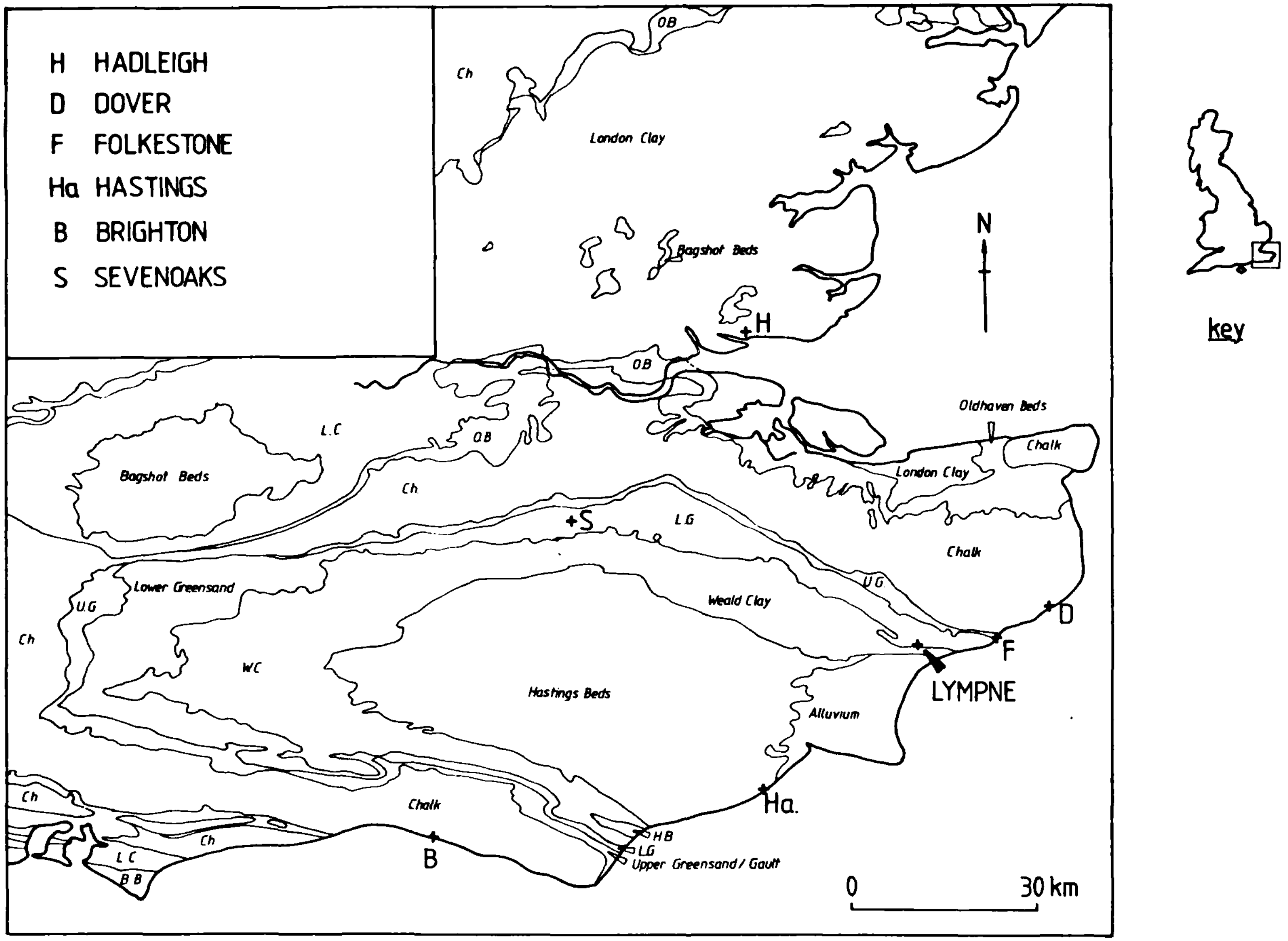
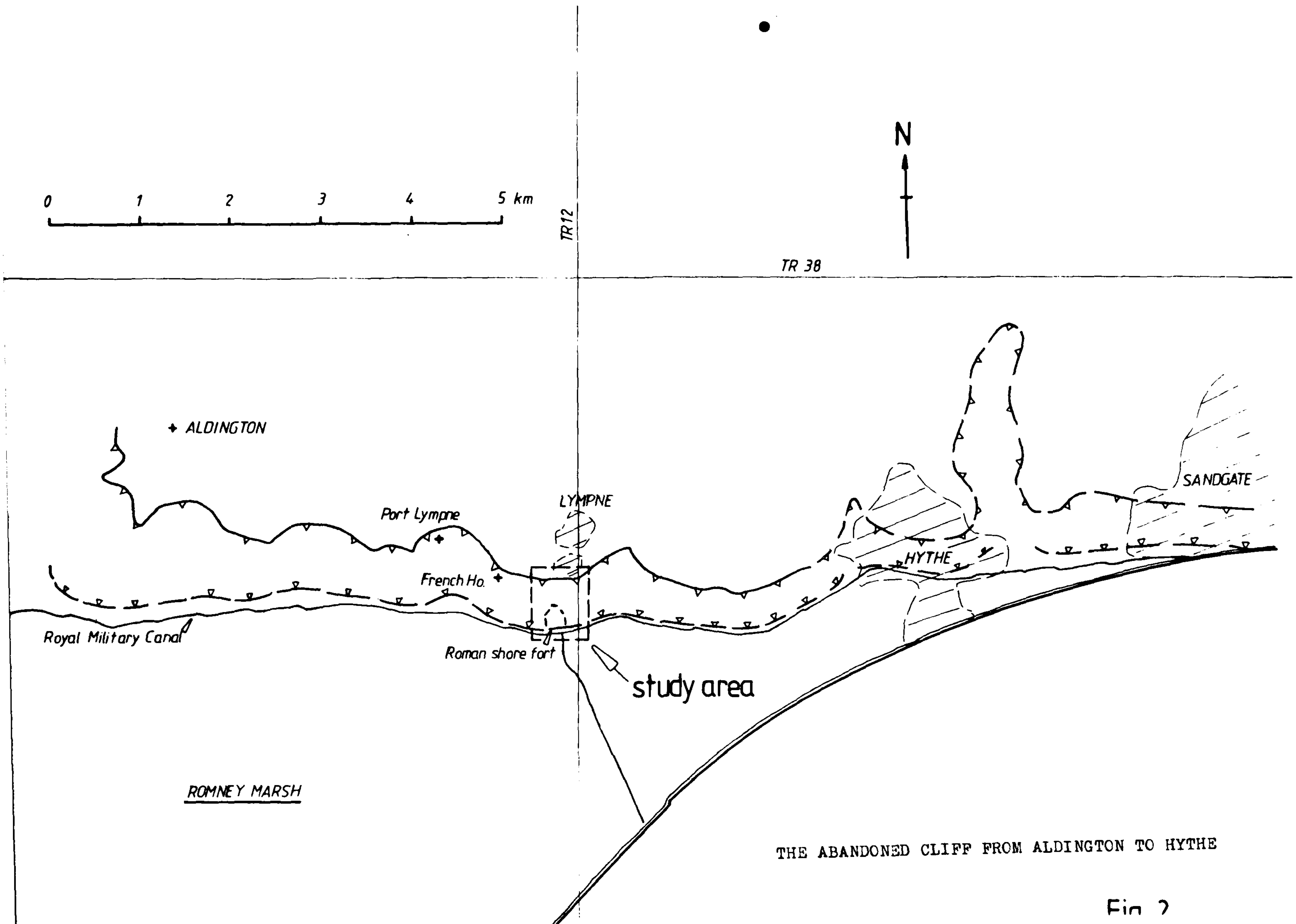


OUTLINE REGIONAL GEOLOGY OF SOUTH-EAST ENGLAND

Fig. 1



THE ABANDONED CLIFF FROM ALDINGTON TO HYTHE

Fig 2

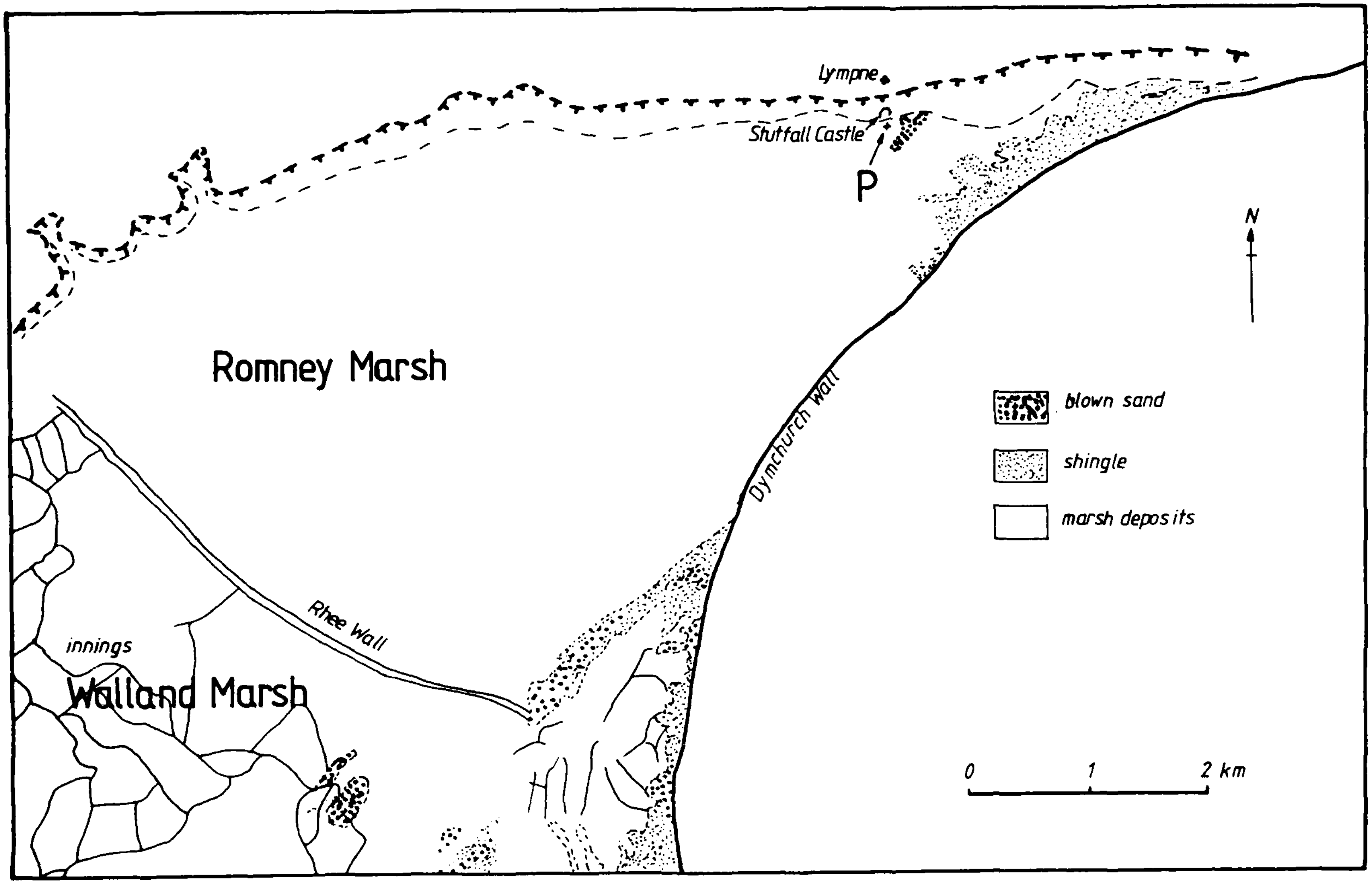
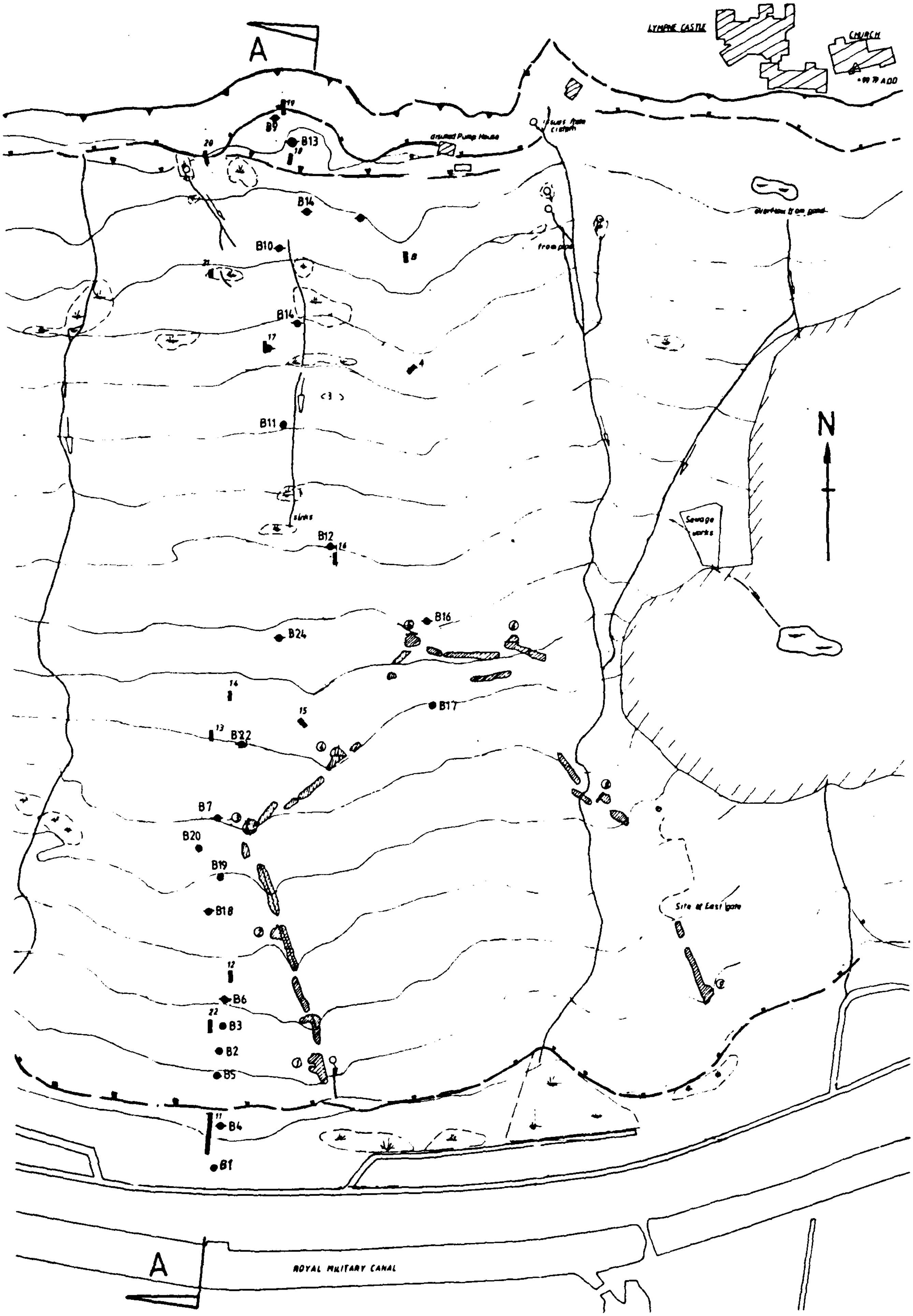
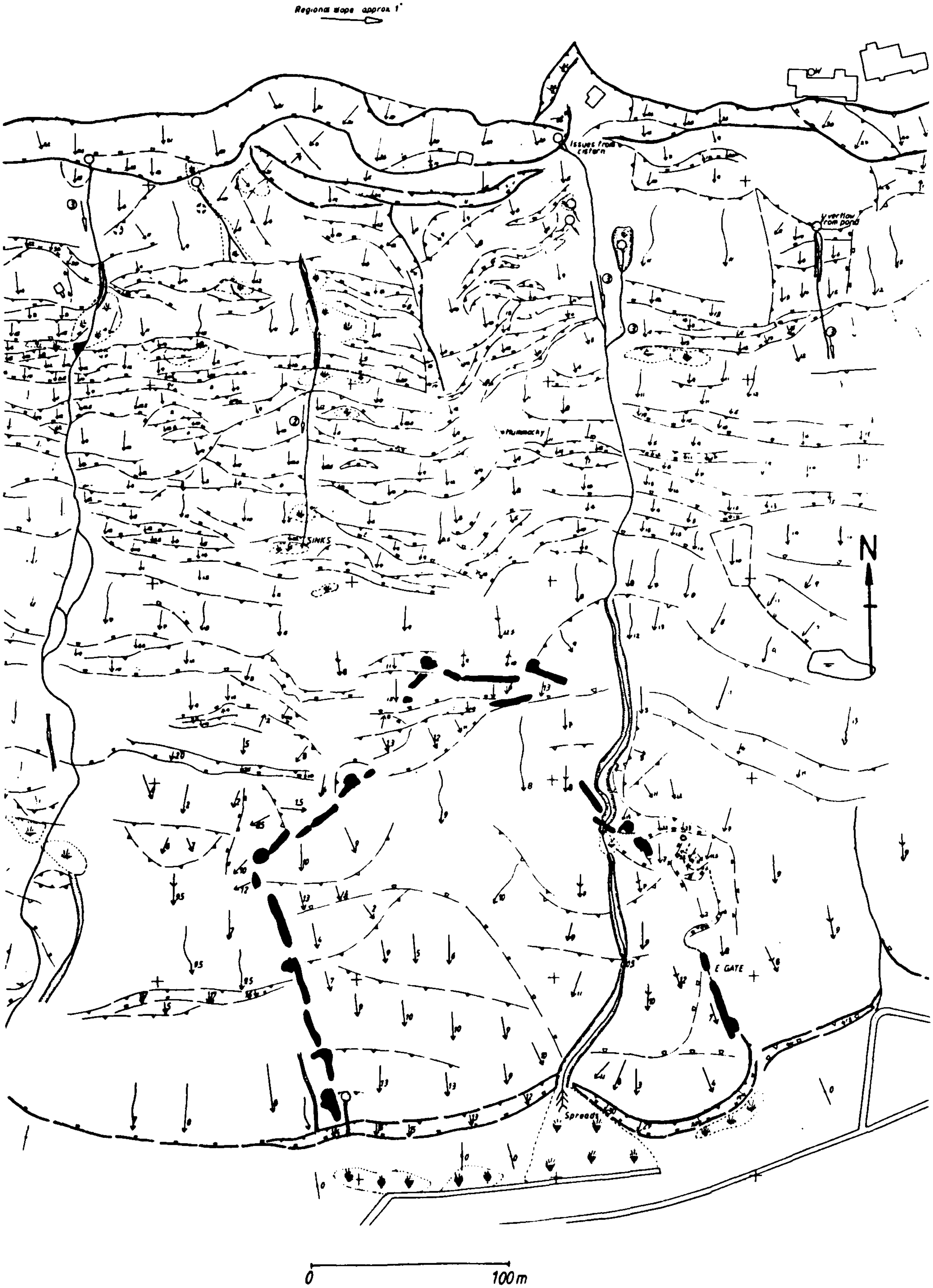

Lympne
Stutfall Castle
P
N
Romney Marsh
Dymchurch Wall
blown sand
shingle
marsh deposits
Rhee Wall
innings
Walland Marsh
0
1
2 km

Fig. 3



A
LYMPNE CASTLE
CHURCH
disused Pump House
issues from cistern
overflow from pond
from pipe
B9
B13
B14
B10
B11
B12
B16
B24
B17
B22
B7
B20
B19
B18
B6
B3
B2
B5
B4
B1
sinks
N
Sewage works
Site of East gate
ROYAL MILITARY CANAL
A

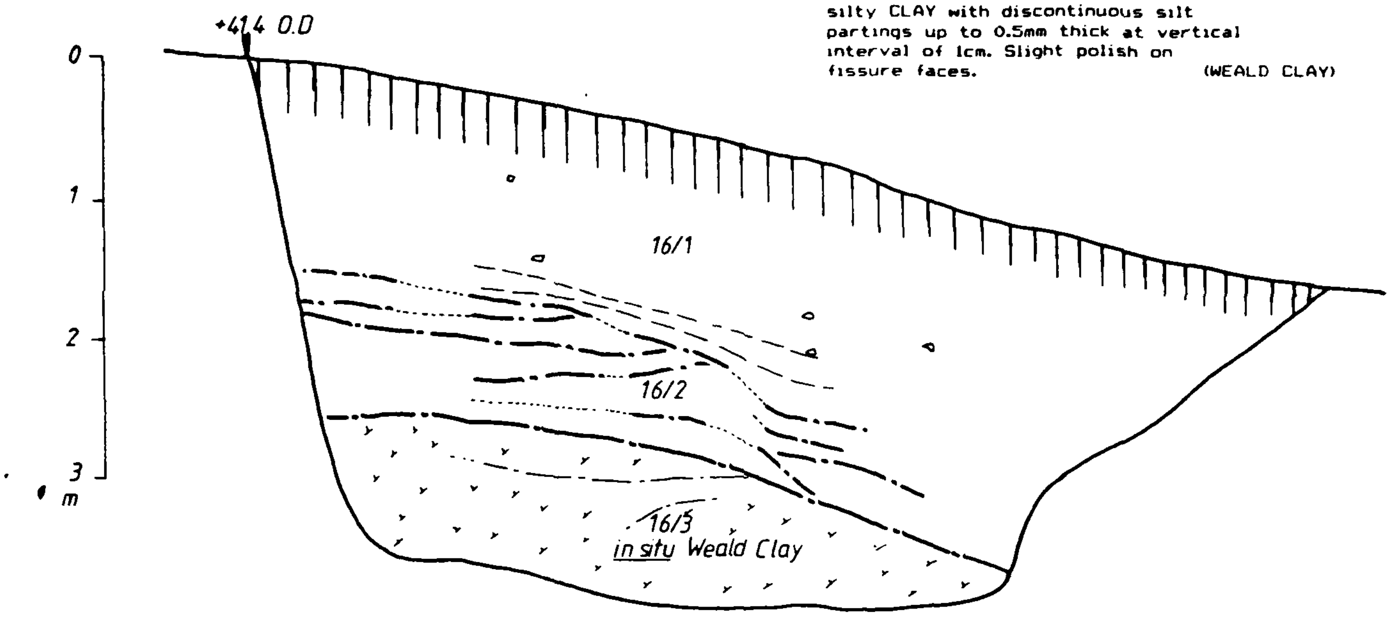

Regional slope approx 1°
Issues from cistern
Overflow from pond
Hummocky
SINKS
E GATE
Spreads
N
0
100m

TRIAL PIT 16

16/1 Stiff fawn structureless silty CLAY with occ. sub-angular rag fragments (COLLUVIUM)

16/2 Stiff grey brown silty CLAY sheared fabric with many slickensided surfaces. (COLLUVIUM)

16/3 Very stiff to hard bluish grey fissured thinly laminated slightly weathered silty CLAY with discontinuous silt partings up to 0.5mm thick at vertical interval of 1cm. Slight polish on fissure faces. (WEALD CLAY)



TRIAL PIT 20

20/1 Friable buff homogenous microfissured clayey SILT becoming slightly more clayey and fissured with depth. (HYTHE BEDS)

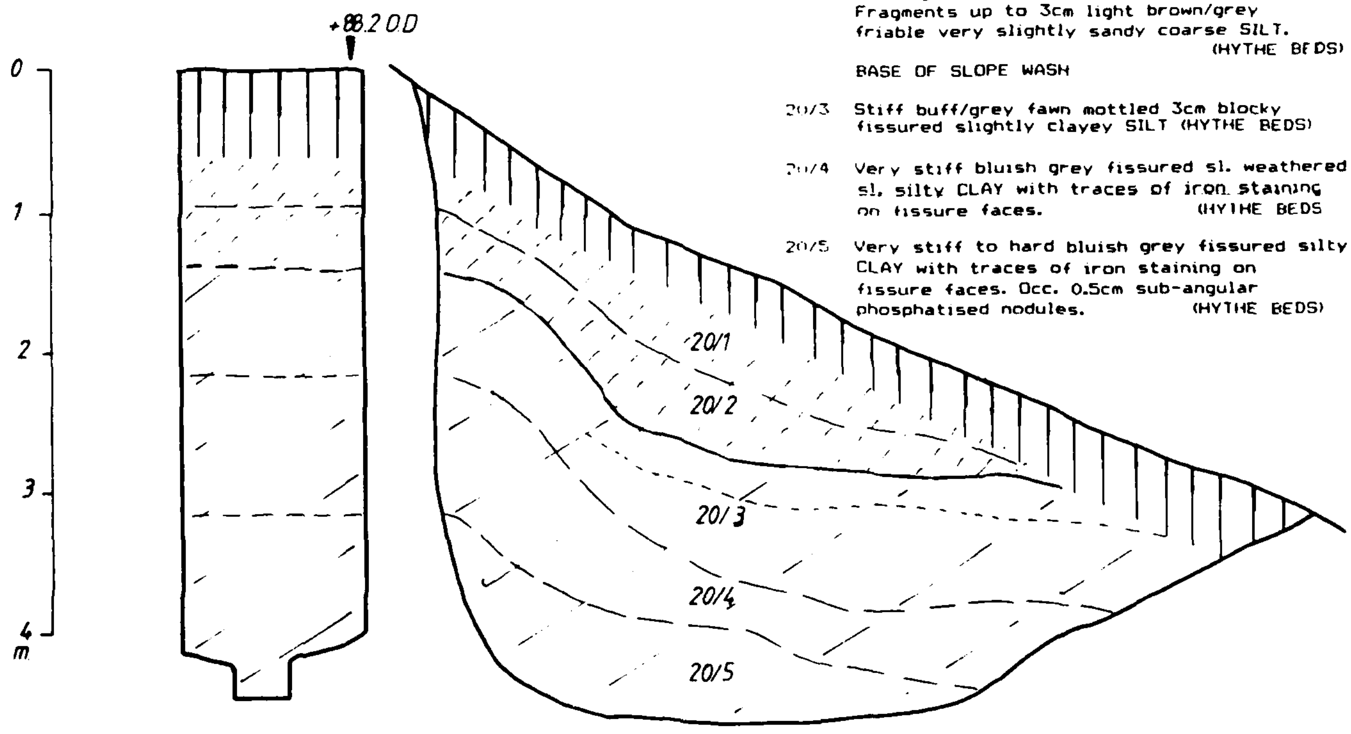
20/2 Firm light brownish grey silty CLAY with 0.5cm grey silty clay banded mottling. Fragments up to 3cm light brown/grey friable very slightly sandy coarse SILT. (HYTHE BEDS)

BASE OF SLOPE WASH

20/3 Stiff buff/grey fawn mottled 3cm blocky fissured slightly clayey SILT (HYTHE BEDS)

20/4 Very stiff bluish grey fissured sl. weathered sl. silty CLAY with traces of iron staining on fissure faces. (HYTHE BEDS)

20/5 Very stiff to hard bluish grey fissured silty CLAY with traces of iron staining on fissure faces. Occ. 0.5cm sub-angular phosphatised nodules. (HYTHE BEDS)



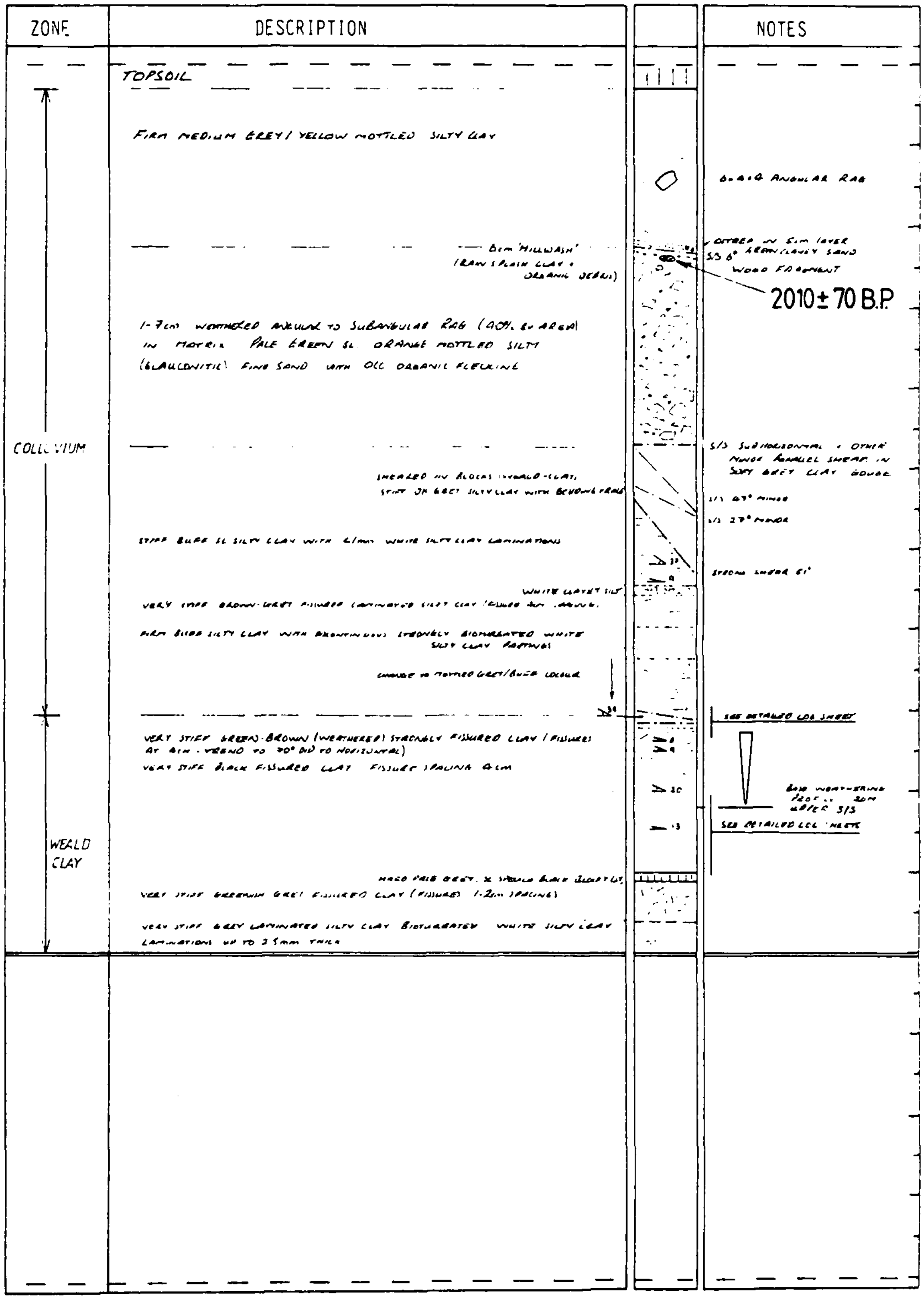
Borehole 16

ZONE	DESCRIPTION		NOTES
COLLUVIUM	TOPSOIL. POORLY DEVELOPED		
	FIRM BUFF-YELLOW BROWN V SL SILTY CLAY WITH POORLY DEVELOPED 5cm FISSURING. OCC 0.5cm LUMP FERRUGINOUS SILTSTONE STIFF	CALCAREOUS SILT	SL ORANGE MOTTLING SL MORE SILTY BELOW 0.5cm SHEAR BANDED SOFT BROWN GREEN CLAY SS SUB HORIZONTAL
	STIFF MEDIUM BROWN GREY MOTTLED SL. SILTY CLAY SHEARED UP SHEARED FABRIC BREAKS DOWN TO 5cm PEDS		SS 10°
WEALD CLAY	BROWN STIFF TO VERY STIFF DARK BROWN STRONGLY FISSURED CLAY 3.5cm FISSURE SPACING. GREY		SS MINOR SUBHORIZONTAL (NUM SHEARS IN 2cm BANDS) BASE OF WEATHERING
	VERY STIFF TO HARD BLACK STRONGLY FISSURED CLAY. FISSURES AT 2cm SPACING TRENDING AT 35° TO HORIZONTAL. BEDDING PLANE SUB-HORIZONTAL WITH OSTRACOD TRACES		rp
	VERY STIFF PALE TO MID GREY CLAY WITH DISCONTINUOUS STRONGLY BIOTURBATED WHITE SILTY CLAY LAMINATIONS		
	PALE GREENISH BROWN INDURATED FINE SANDY SILT		13° DIP
	VERY STIFF TO HARD PALE GREY LAMINATED FISSURED CLAY. BLOCKY 5cm FISSURES. LAMS 2mm THICK AT 3cm SPACING OF WHITE SILTY CLAY		SS 20° (VISUALLY OLD) CONTACT DIPS 15°
	VERY STIFF TO HARD DARK GREY FISSURED CLAY. FISSURE SPACING 1.5-2.5 cm. OCC 4cm 'FISSURE' BLOCK OLIVE GREEN/GREY CLAY WITH POLISHED FACES. PASSES DOWN TO: HARD SL OLIVE HUE GREY/BLACK SL. SILTY CLAY WITH WHITE SILT. STRONGLY BIOTURBATED WHITE SILT PARTINGS		SUB-HORIZONTAL BEDDING 1cm PEBBLE OF [illegible] MATERIAL EROSIONAL CONTACT IN WEALD CLAY
	VERY HARD PALE GREY. OCC BUFF MOTTLED. FISSURED SL. CLAYEY SILT. 5cm FISSURING WITH OCC TRACE OF OLIVE-BUFF/GREY STAIN ON SUBVERTICAL FISSURES		MORE SILTY WITH DEPTH
	CONTINUATION FISSURING 5cm WITH 0.5mm BUFF-OLIVE STAINING. OCC. 1cm PATCHES REDDISH FERRUGINOUS STAINING		

LYMPNE

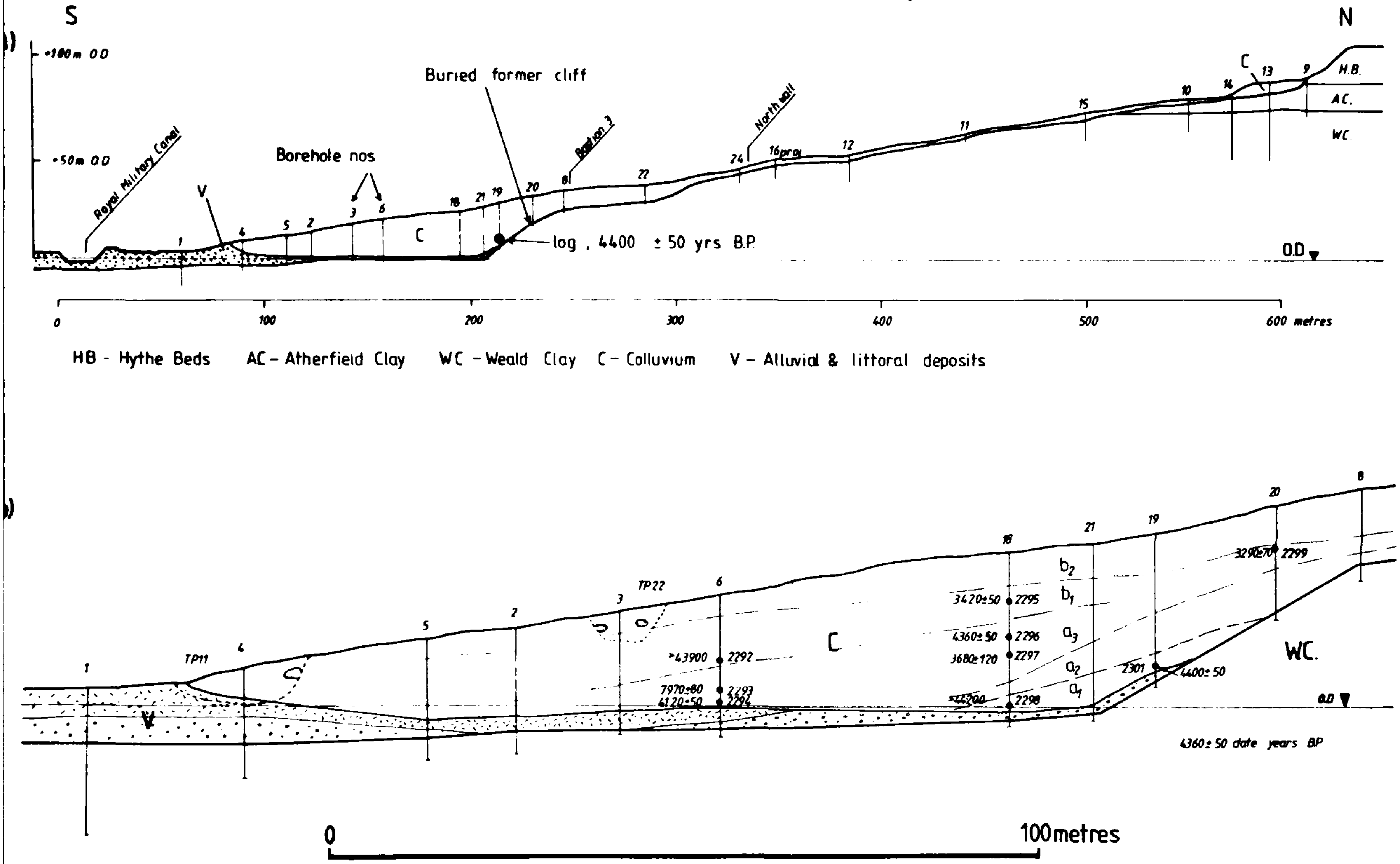
Fig. 7

Borehole 22



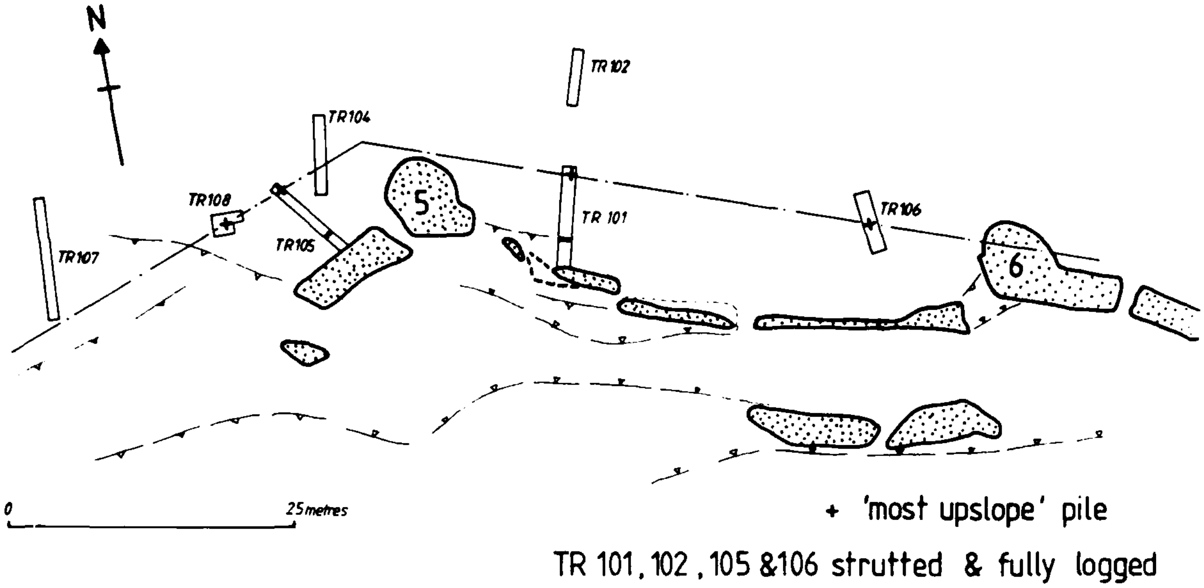
LYMPNE

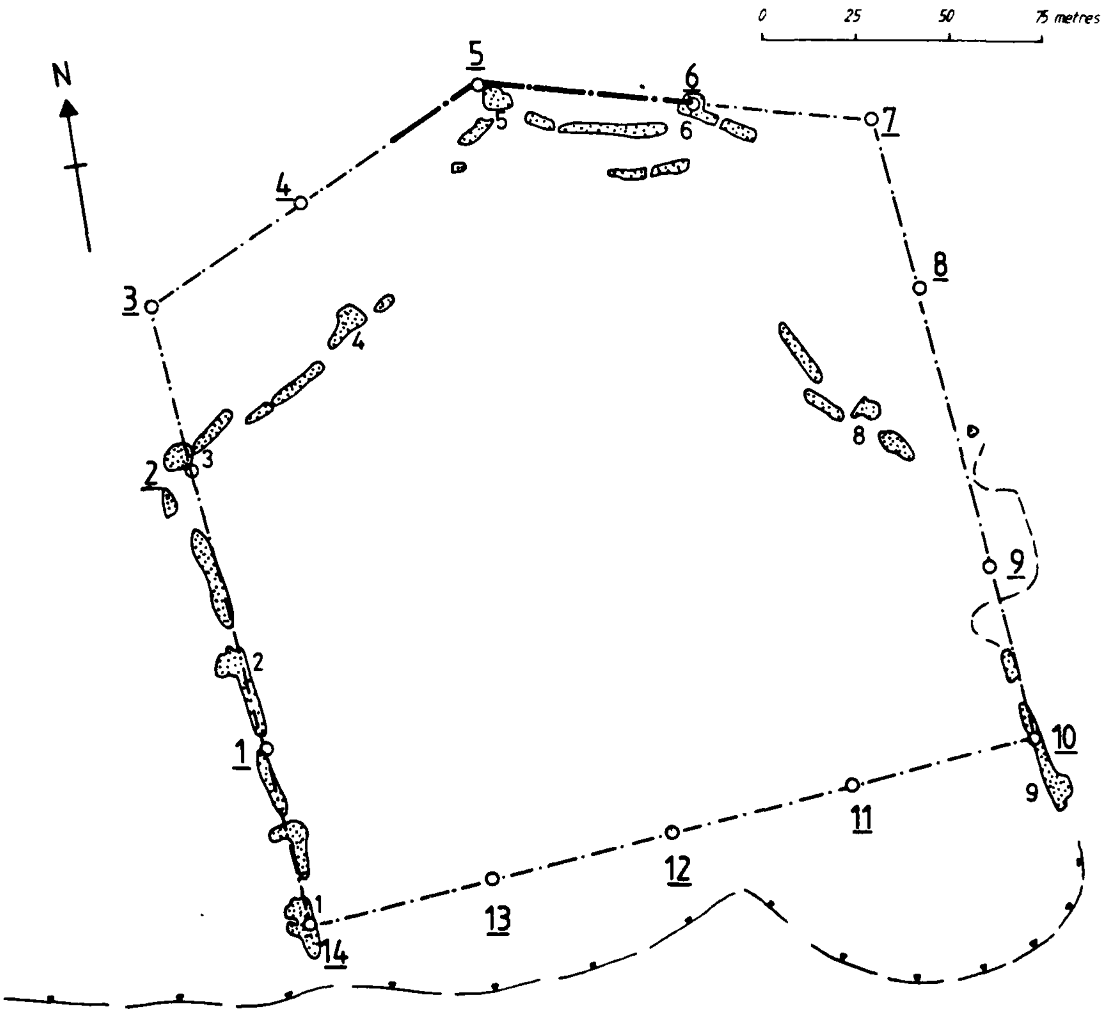
Fig. 8



a) SECTION A-A b) DETAIL OF LOWER PART OF SLOPE

Fig. 9





6 reconstructed bastion position
6 present-day bastion position

Fig. 10

TR 101 EAST ELEVATION

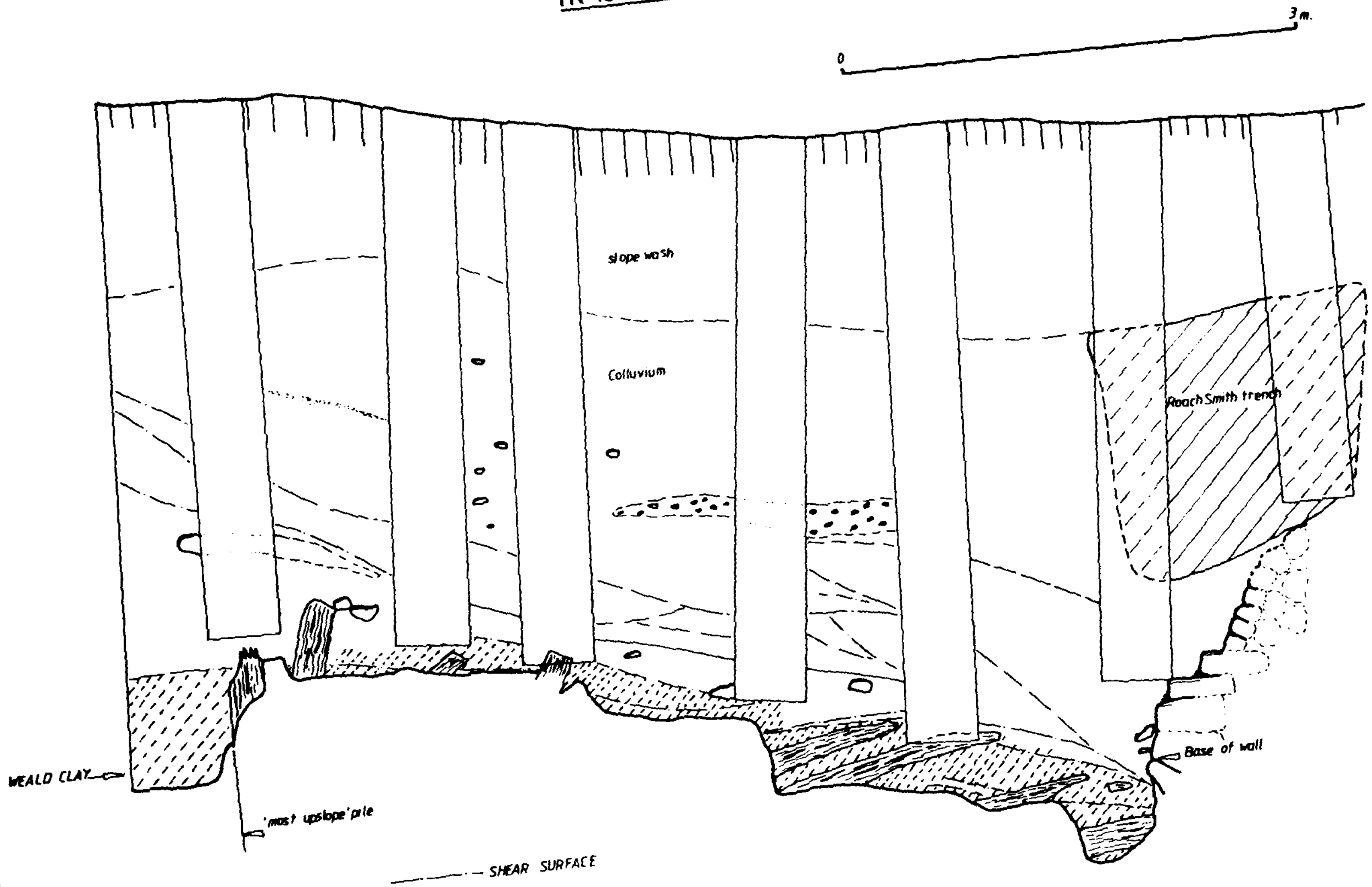
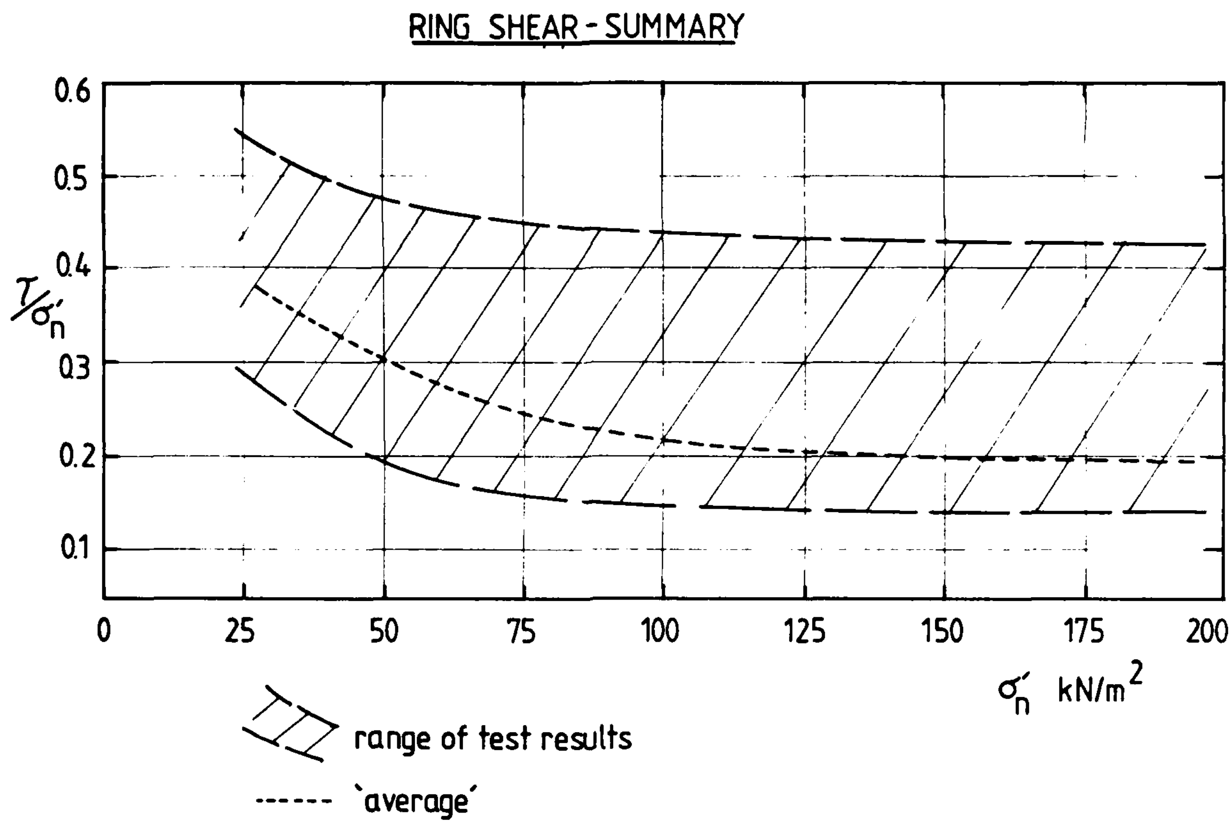
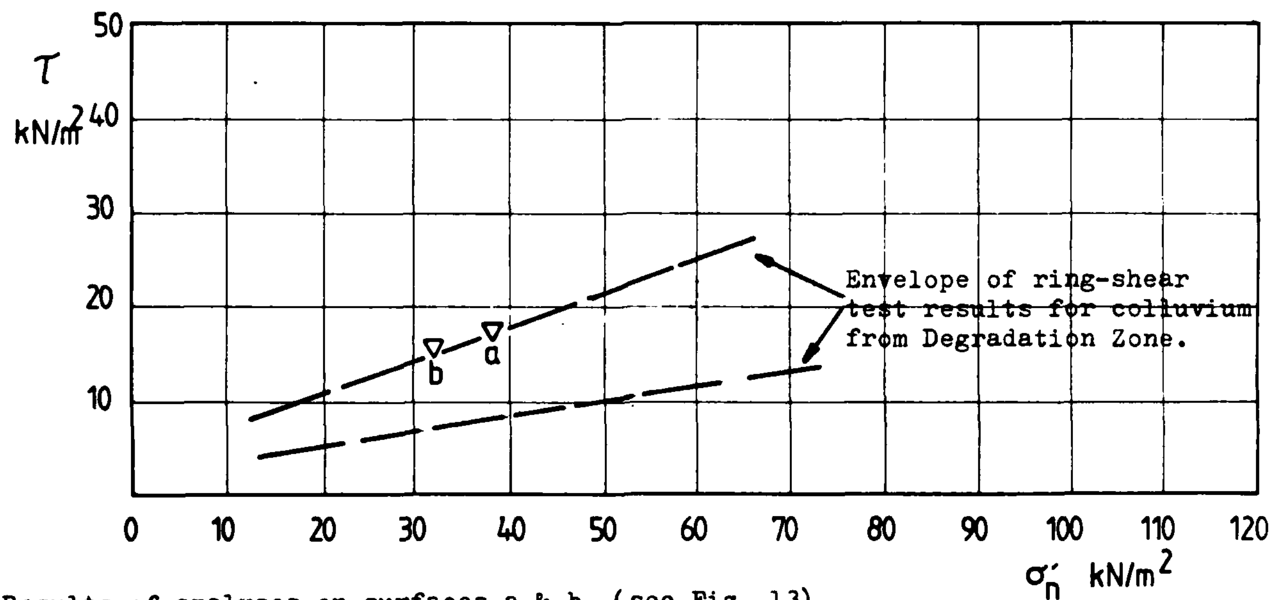


Fig. 11



a) Laboratory ring-shear test results overall range for 27no. tests with 'average' test result for purely Weald Clay derived colluvium.



b) Results of analyses on surfaces a & b (see Fig. 13)

Fig. 12

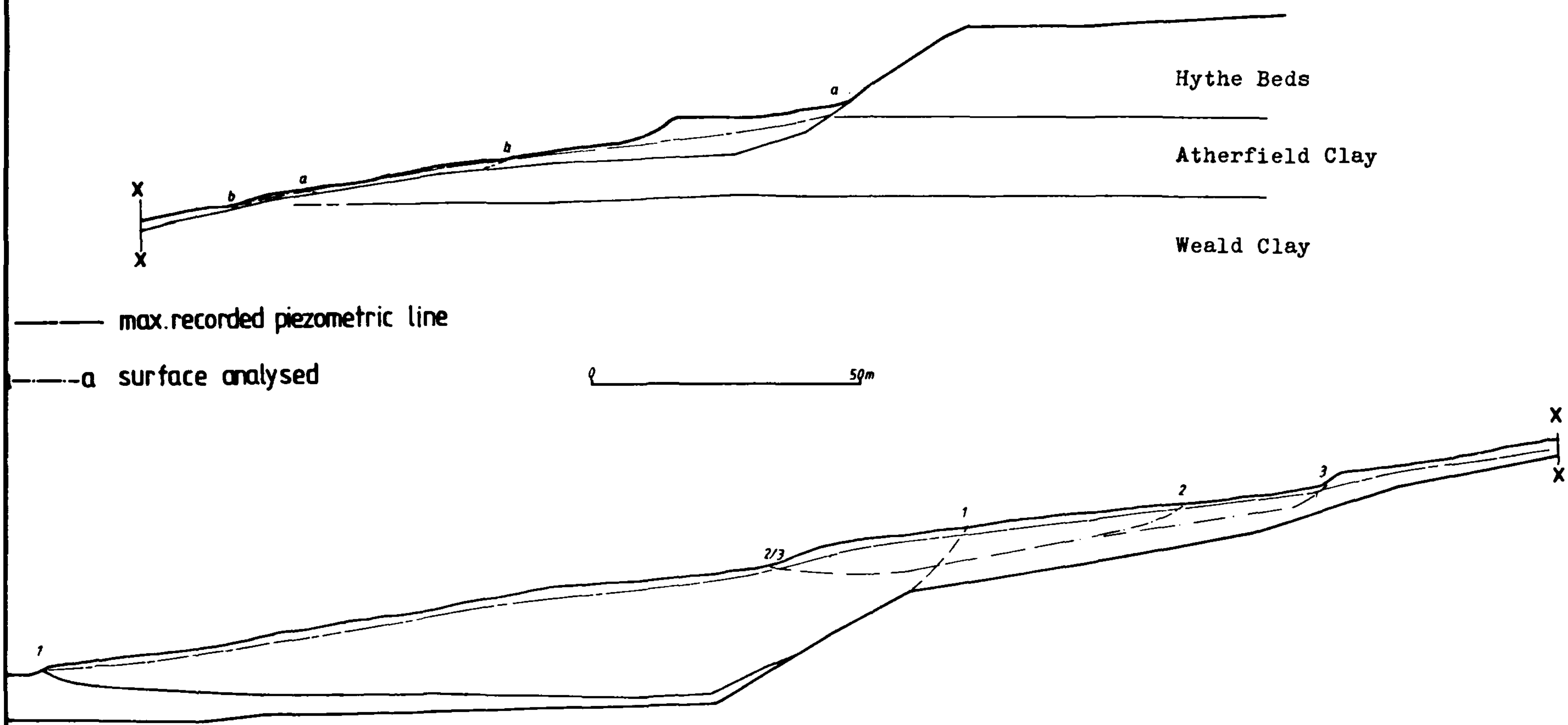
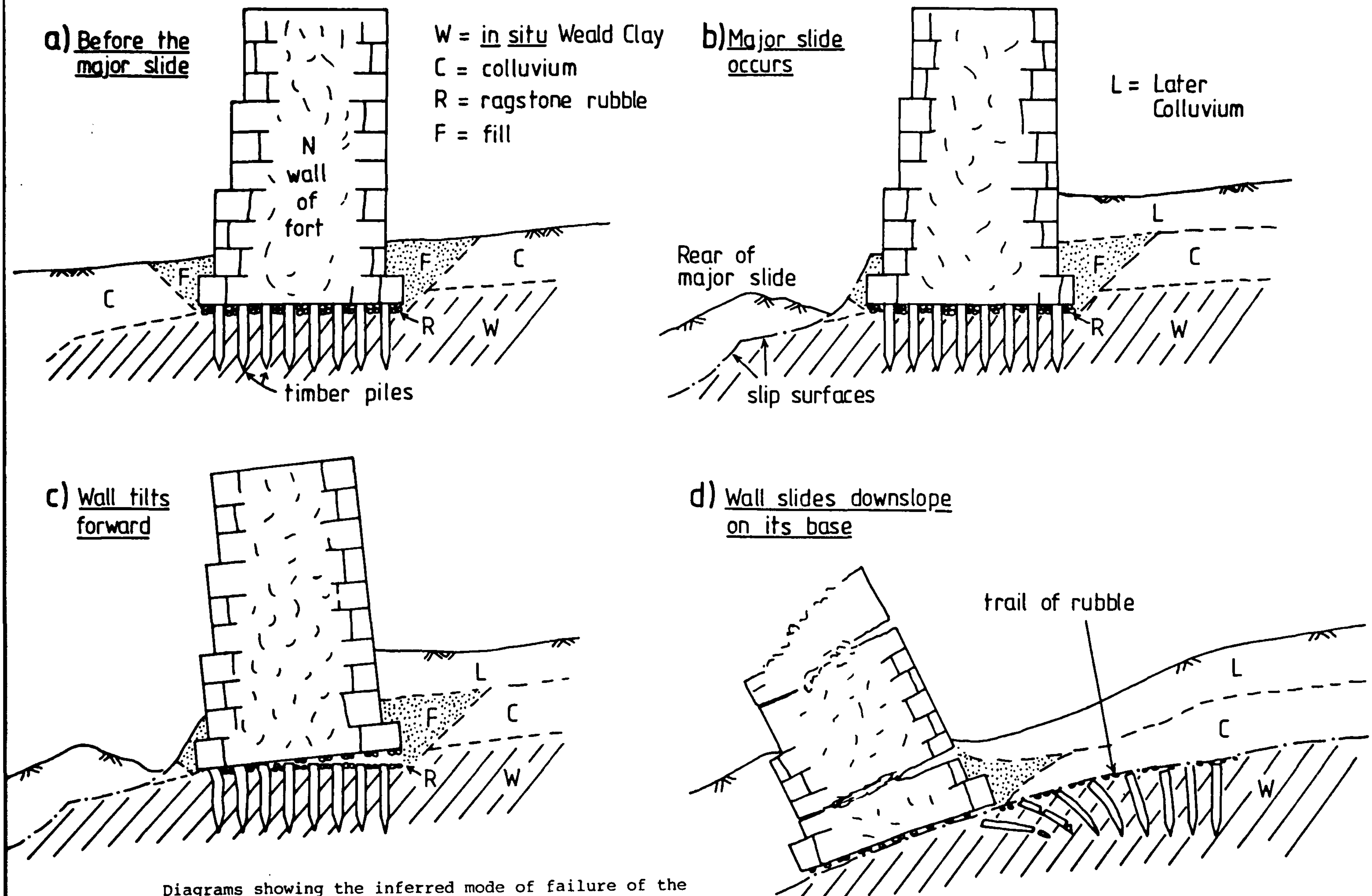

Hythe Beds
Atherfield Clay
Weald Clay
X
X
a
b
a
b
max. recorded piezometric line
a surface analysed
0
50m
X
X
1
2/3
1
2
3

Fig. 13



Diagrams showing the inferred mode of failure of the north wall of the fort.

Fig. 14.

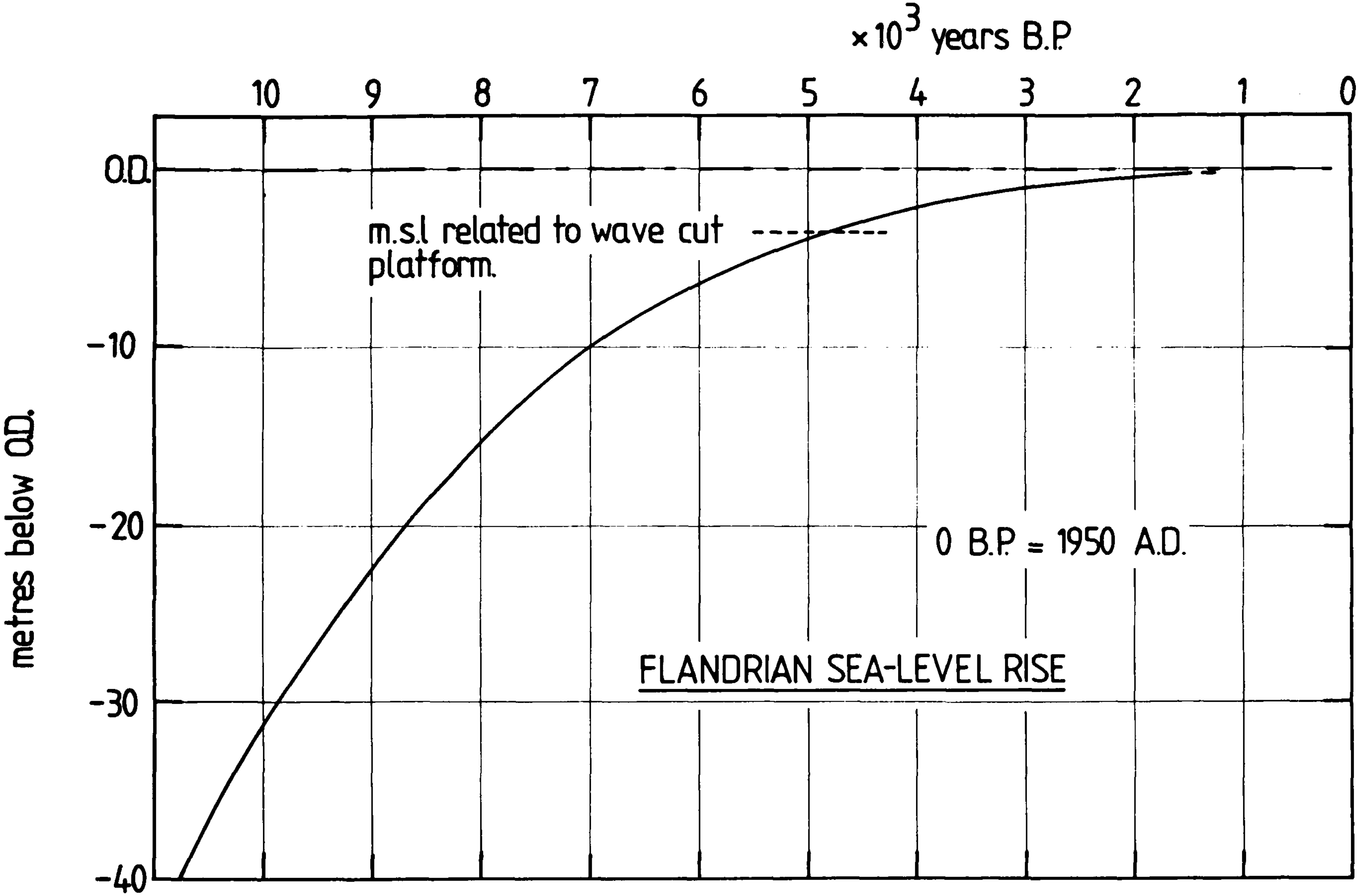
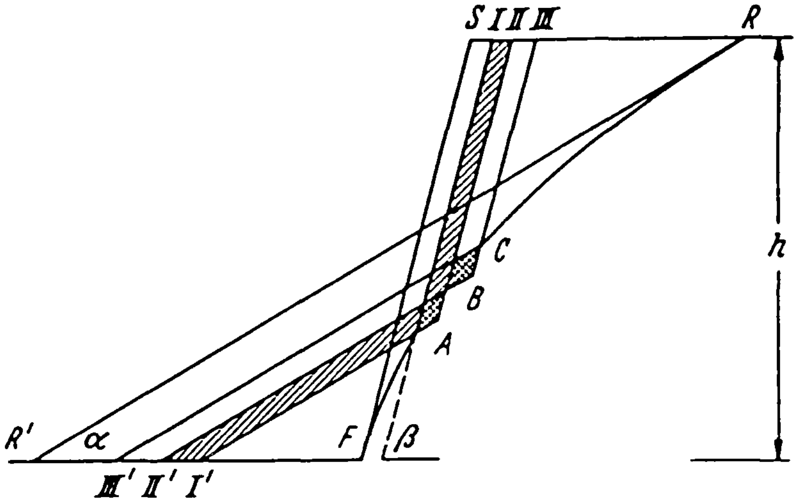
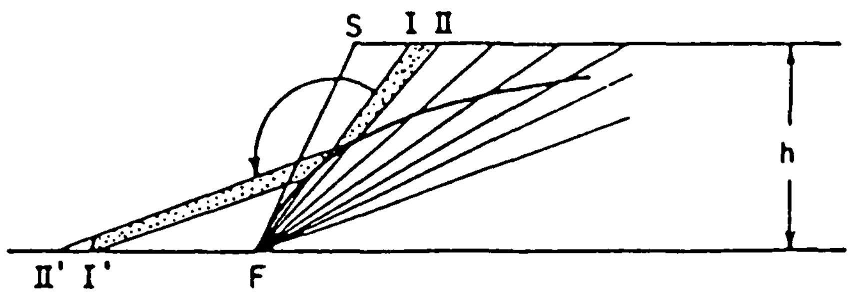

$\times 10^3$ years B.P
10
9
8
7
6
5
4
3
2
1
0
O.D.
-10
-20
-30
-40
metres below O.D.
m.s.l related to wave cut platform.
0 B.P. = 1950 A.D.
FLANDRIAN SEA-LEVEL RISE

Fig. 15



FISHER-LEHMANN



BAKKER & Le HEUX

END

FILMED

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